AN ABSTRACT OF THE THESIS OF

RONALD EDMOND DAVENPORT for the DOCTOR OF PHILOSOPHY
(Name) (Degree)

in GEOLOGY presented on June 5, 1970
(Major) (Date)

Title: GEOLOGY OF THE RATTLESNAKE AND OLDER IGNIMBRITES IN THE PAULINA BASIN AND ADJACENT AREA, CENTRAL OREGON

Abstract approved: Redacted for privacy
Harold E. Enlows

The area of this investigation lies on the south side of the Ochoco Uplift in central Oregon; it includes the Paulina Basin and the southwestern part of the John Day Uplift.

This study concentrates on four ignimbrites, each less than 100 feet thick. The lower ignimbrite (15.8 m.y.) belongs to the Mascall Formation of Miocene age; the remaining three have been assigned to the Danforth Formation of Pliocene age and are referred to as the crystal-rich (lower unit, 9.2 m.y.), the crystal-poor, and the Rattlesnake ignimbrite (upper unit, 6.1 m.y.) members. The Mio-Pliocene boundary in the Paulina Basin is placed at the base of the crystal-rich ignimbrite, i.e., the base of the Danforth, on the basis of its radiometric age and mammalian fossils found in associated sediments.

The four ignimbrites are vitric tuffs and can be distinguished by

their lithologies or by using petrographic methods. They are rhyolitic in composition, the silica content ranging from 73 to 78 percent. Although composed largely of glass, crystal fragments of alkali feldspar, quartz, magnetite, clinopyroxene, and zircon are common. Phenocrysts commonly form one to five percent of the rock but range from 0 to 18 percent. The Rattlesnake ignimbrite contains a small amount of black latitic pumice that has a mineral assemblage of plagioclase, olivine, and augite.

Pliocene ignimbrites of the Paulina Basin are correlative to three ignimbrite members of the Danforth Formation exposed in Devine Canyon north of Burns, Oregon. The Rattlesnake ignimbrite member is also equivalent to the ignimbrite member of the Rattlesnake Formation in the John Day Valley. This correlation is supported by lithologic and petrographic similarities, mammalian fossils, potassium-argon age dates, geomagnetic polarity, chemical composition, stratigraphic position and alkali feldspar compositions.

The Rattlesnake ignimbrite extends over approximately 6500 square miles in the valleys of the John Day River, North and South Forks of the John Day River, Mountain Creek, Murderers Creek, Paulina area, Bear Valley, and the Harney Basin. It has an average thickness of 45 feet and a volume in excess of 55 cubic miles. The source for the Rattlesnake ignimbrite is thought to be in the Harney Basin. This is indicated by an increase in the thickness, welding, devitrification, vapor phase mineralization, and potash content of the alkali feldspars toward the basin. Mixing of magmas is indicated by the presence of banded pumice of rhyolitic to latitic composition in the Rattlesnake ignimbrite.

Geology of the Rattlesnake and Older Ignimbrites in the Paulina Basin and Adjacent Area, Central Oregon

by

Ronald Edmond Davenport

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

June 1971

APPROVED:

Redacted for privacy

Associate Professor of Geology

in charge of major

Redacted for privacy

Acting Chairman of Department of Geology

Redacted for privacy

Dean of Graduate School

Date thesis is presented June 5, 1970

Typed by Clover Redfern for Ronald Edmond Davenport

ACKNOWLEDGMENTS

The writer wishes to express his sincere gratitude to his major professor, Dr. H. E. Enlows, for suggesting this problem and providing financial assistance from NSF Grant GA-1163, for criticism, and for his encouragement throughout this investigation. Appreciation is also extended to Dr. E. M. Taylor and Dr. K. F. Oles for critically reading the manuscript. In addition the author thanks Dr. E. M. Taylor and Mr. Monty Elliott for providing chemical analyses.

The writer gratefully acknowledges the help of the late Dr. W. D. Wilkinson who had a keen interest in the problem and who offered encouragement and valuable advice. Thanks are also due George W. Walker, who visited the writer in the field and offered freely of his ideas and information, and to Dr. J. A. Shotwell for the identification of the mammalian fossils collected.

The writer is grateful to his wife Elizabeth, for her constant encouragement and patience throughout this study. Her companionship in the field, assistance with other phases of the study, and the typing of many rough drafts is deeply appreciated.

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GEOLOGY OF THE RATTLESNAKE AND OLDER IGNIMBRITES IN THE PAULINA BASIN AND ADJACENT AREA, CENTRAL OREGON

INTRODUCTION

Purpose

The purposes of this investigation are: 1) to determine the number and stratigraphic position of the Tertiary ignimbrites in the Paulina Basin and adjacent area; 2) to ascertain their age by radiometric dating and associated fossil evidence; 3) to determine if the ignimbrite previously assigned to the Rattlesnake Formation in the Paulina Basin is equivalent to the ignimbrite member of the Rattlesnake Formation in the John Day Valley; 4) to determine the Mio-Pliocene boundary in the Paulina Basin stratigraphic sequence; 5) to investigate a possible source for the ignimbrites in the Paulina Basin and adjacent area.

Location and Geologic Setting

The area of study includes approximately 660 square miles. It is located in Crook, Grant, and Harney Counties, central Oregon (Figure 1) and includes the area between longitude 119°30' and 120°03'40" W. and latitude 43°55'40" and 44°13'20" N. Paulina and Rager Ranger Station are the only communities in the area. The area

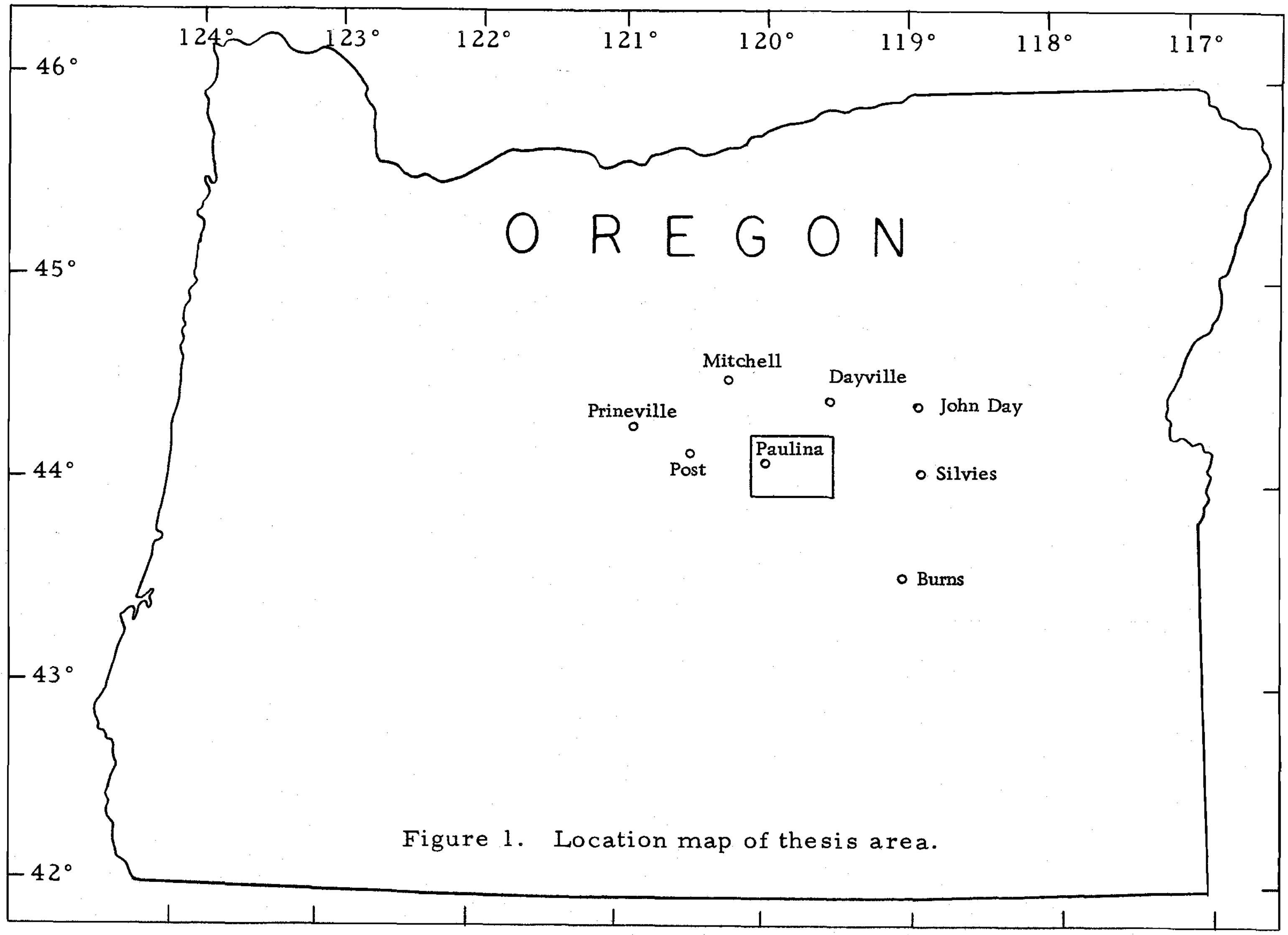


Figure 1. Location map of thesis area.

is readily accessible by road from several directions. A hard-surfaced road along the Crooked River connects Prineville, Post, and Paulina.

The area of this investigation is on the south flank of the Ochoco Uplift. It includes the region in the upper Crooked River Basin designated by Brown and Thayer (1966) as the Paulina Basin and the southwestern part of the John Day Uplift (Buddenhagen, 1967). The above two areas have quite different rocks, structure, and geomorphology, but common to both are extensive Pliocene ash-flow sheets that once covered their surfaces and remain as remnants capping the uplands.

The strata of the John Day Uplift consist of predominantly marine deposits of Paleozoic and Mesozoic age that form a large inlier in the Tertiary sedimentary and extrusive volcanic rocks. The southwestern corner of this inlier has been the object of many geologic investigations, the most recent of which are Buddenhagen (1967), and Dickinson and Vigrass (1965). The latter (page 1) describe the rocks of this area in the following terms:

> The composite stratigraphic sequence includes at least 35,000 feet of Paleozoic, Mesozoic, and Cenozoic strata. Both the pre-Cenozoic marine strata and the Cenozoic continental strata include a high proportion of volcanic material, largely pyroclastic in the Mesozoic beds. Twelve unconformities break the continuity of the sequence and local facies changes are prominent in the marine strata. Repeated diastrophism, which was strongest in the Permian-Triassic, Early Jurassic, and Jurassic-Cretaceous

> times, has produced a complexly folded and faulted terrane in which the degree of deformation is roughly proportional to age.

The Tertiary rocks resting on the above pre-Cenozoic sequence are basalts, gravels, and welded tuffs of Miocene and Pliocene age.

The Paulina Basin and adjacent Crooked River Valley region has been the object of geologic thesis problems for master's candidates at Oregon State College (University since 1961) (Bowman, 1940; Brogan, 1952; Forth, 1965; Lowry, 1940; Mote, 1939). The rocks in this area are nearly horizontal and include a wide variety of volcanic derived sedimentary rocks, basalts, and ignimbrites which range in age from Eocene to Holocene (Plate I in pocket).

History of Previous Investigations

Clarence King reported in 1870 that Miocene rocks containing large quantities of mammalian fauna were abundant on the Crooked, the John Day and the Malheur Rivers. During the summers of 1899, 1900, and 1901 J. C. Merriam led expeditions into central Oregon for the purpose of collecting vertebrate fossils from Tertiary rocks. In his subsequent report, "A Contribution to the Geology of the John Day Basin" (Merriam, 1901), he named a sequence of gravels, ash, tuff, and rhyolite the Rattlesnake Formation. It rests with angular unconformity on the Mascall Formation of Miocene age. The type locality for the Rattlesnake Formation was given as Rattlesnake Creek west of Dayville, Oregon. At that time no fossil lists were published for the Rattlesnake Formation because most fossil localities revealed what was thought to be a mixed assemblage of Mascall and Rattlesnake fauna. However, the Rattlesnake was tentatively assigned to the Pliocene due to its stratigraphic position relative to the Mascall (Merriam, 1901).

Many rock samples were collected on these early expeditions. A member of the party, F. C. Calkins (1902) studied these and wrote a report entitled "A Contribution to the Petrography of the John Day Basin." It was in this report that Calkins presents the following discussion on the petrography of the Rattlesnake Formation:

> This lies in almost horizontal attitude upon the tilted and truncated Mascall beds in the elongated area mentioned above. Dr. Merriam named this formation and considered it to be of fluviatile origin in large part, and comprises a large amount of coarse gravel and sandstone, together with fine material that may be tuffaceous. Somewhere near the middle of the section there occurs a widely spread sheet of light colored pumiceous tuff, overlaid by a glassy gray rhyolite.

It was half a century later that Wilkinson (1950) suggested that this widespread sheet of pumiceous tuff and glassy gray rhyolite was actually an ignimbrite or ash-flow tuff.

Rattlesnake Correlative in the Crooked River Region

Correlations were made between the Tertiary strata of the John

Day Valley and the Crooked River Basin as early as 1870 by Thomas Condon, a pastor at the Congregational Church at The Dalles (Merriam, 1901). L. S. Davis and V. C. Osmont, who were field assistants for Merriam, collected fossils in the Crooked River and Logan Butte areas in the fall of 1900. Osmont subsequently conveyed to Merriam the idea that the rhyolite which caps the Mascall beds in the Crooked River region is equivalent to the rhyolite member of the Rattlesnake Formation in the John Day Valley.

W. D. Wilkinson was the geologist-in-charge of a field party mapping the Round Mountain Quadrangle in the late 1930's. He made tentative correlations with the Mascall Formation of the John Day Valley on the basis that the Crooked River beds were similar in lithology, stratigraphic position, and contained a similar fauna (Wilkinson, 1939). The Rattlesnake correlation of the "highly consolidated rhyolitic tuff" was made on the basis of similar lithology. The occurrence of the Rattlesnake ignimbrite south of the Ochocos has also been reported by Chaney (1927), Hodge (1942), Thayer (1952), Wallace and Calkins (1956), Dickinson and Vigrass (1965) and Brown and Thayer (1966). These were all made on the basis of the same lithology and structural relations, and can be considered superficial in view of the lack of supporting data.

Sources of previous geologic mapping in the thesis area are presented in Figure 2. Much of the mapping was done by Oregon

Figure 2. Sources of previous geologic mapping within the area of study (numbers correspond to the appropriate area below).

1) Bowman, 1940, OSC Master's Thesis

2) Brogan, 1952, OSU Master's Thesis

3) Brown and Thayer, 1966

4) Dickinson and Vigrass, 1965

5) Forth, 1965, OSU Master's Thesis

6) McKitrick, 1934, OSC Master's Thesis

7) Mote, 1939, OSC Master's Thesis

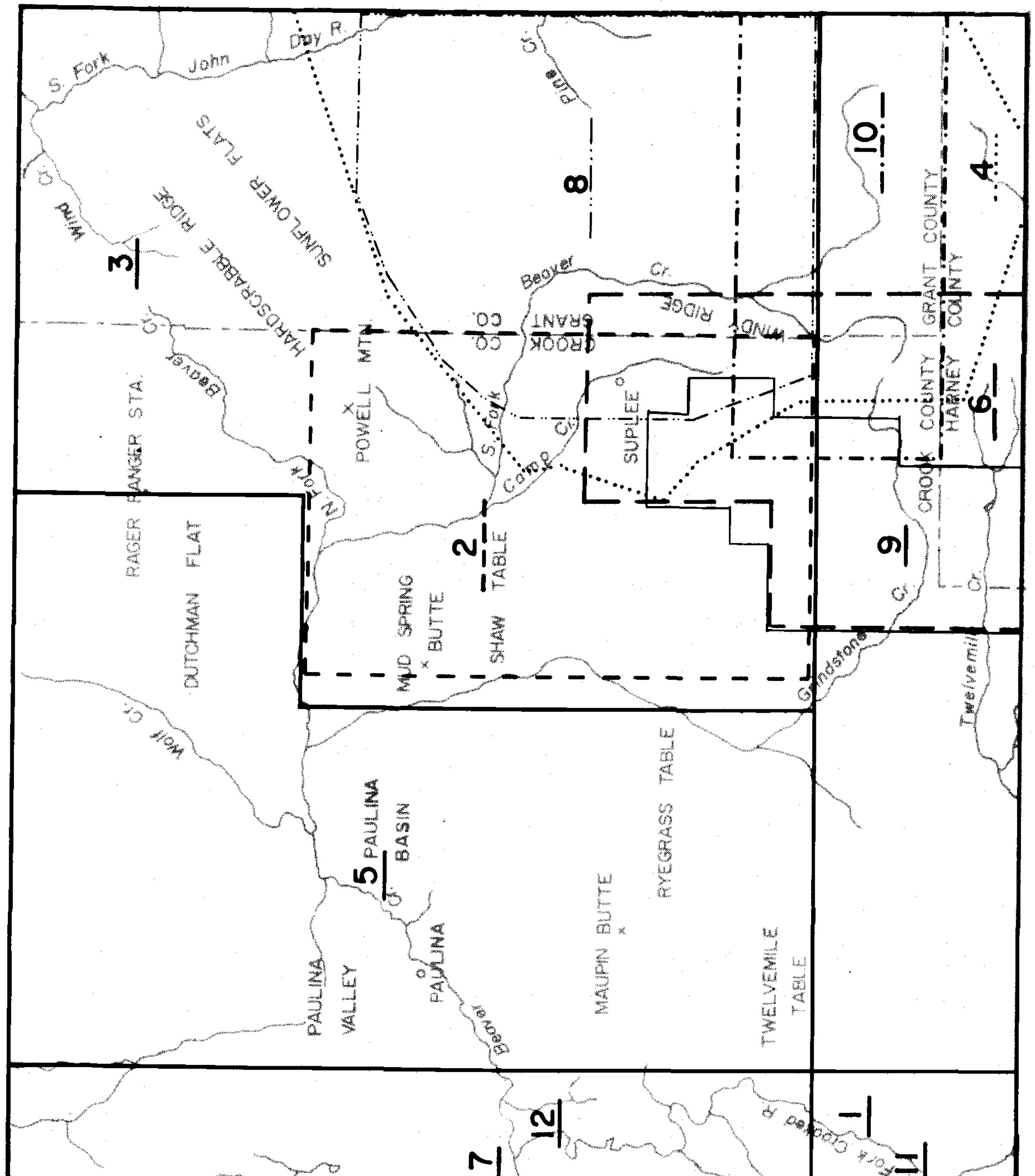
8) Nesbit, 1951, OSC Master's Thesis

9) Ogren, 1958, OSC Master's Thesis

10) Waisgerber, 1956, OSC Master's Thesis

11) Walker, Peterson, and Greene, 1967

12) Wilkinson, 1939



S. Fork
John
Day R.
Pine Cr.
Wind Cr.
SUNFLOWER FLATS
HARDSCRABBLE RIDGE
3
8
10
4
Beaver Cr.
GRANT CO.
CROOK CO.
WINDY RIDGE
GRANT COUNTY
HARNEY COUNTY
CROOK COUNTY
POWELL MTN.
SUPLEE
S. Fork
Camp Cr.
RAGER RANGER STA.
Beaver Cr.
N. Fork
6
2
9
TABLE
SHAW
MUD SPRING BUTTE
DUTCHMAN FLAT
Grindstone Cr.
Twelvemile Cr.
Wolf Cr.
5
PAULINA BASIN
PAULINA
PAULINA VALLEY
MAUPIN BUTTE
RYEGRASS TABLE
TWELVEMILE TABLE
Beaver Cr.
12
7
1
11
S. Fork Crooked R.

State College master's candidates. Some authors (Wilkinson, 1939; Mote, 1939; Bowman, 1940; Brogan, 1952) have designated the upper ignimbrite (Rattlesnake) as correlative to the Harney Formation of Pliocene age that crops out to the southeast in the Harney Basin. This is no longer considered an accurate correlation.

Forth (1965) mapped a large part of the southwest quarter of the Dayville Quadrangle. He reported three ignimbrites in the Mascall Formation and two in the Rattlesnake Formation. Dickinson and Vigrass (1965, report based on their Ph. D. dissertations) recognized the possibility of the Rattlesnake and another ignimbrite occurring in the Suplee-Izee area. Brogan (1952), who mapped the southeast part of the Dayville Quadrangle, reported only one ignimbrite.

Methods of Investigation

The geologic field work was conducted over a period of 18 weeks during the summers of 1968 and 1969. Geologic mapping was done on aerial photographs at the scale of 1:60,000 north of latitude 44°00' N., and a scale of 1:54,000 to the south. The data was subsequently transferred to a 1:62,500 base map assembled from maps provided by the United States Forest Service and the Bureau of Land Management offices in Prineville, Ore. Mapping was restricted to the Cenozoic rocks. The older rocks have been mapped in detail by Dickinson and Vigrass (1965) and Buddenhagen (1967).

In addition to rock samples collected in the thesis area, samples were collected from three ignimbrite members of the Danforth Formation exposed in Devine Canyon north of Burns, Oregon along U. S. Highway 395. These were collected for comparison with the Paulina Basin ignimbrites and the ignimbrite member of the Rattlesnake Formation from the John Day Valley.

Two hundred and three thin sections were prepared for study from the rock samples collected. One hundred and ninety-three were from the Paulina Basin area and ten were from Devine Canyon. Dr. H. E. Enlows supplied many thin sections from the John Day Valley.

Point counting was done with a Leitz mechanical point counting stage on standard-size thin sections utilizing an area of 20 mm by 30 mm and a spacing of 1.0 mm and 0.5 mm. The average number of point counts per section was 1265.

Crystal count studies were conducted on several poorly-welded samples. These were prepared by 1) shaking apart with the ro-tap during sieving, or 2) crushing with the Chipmunk Rock Crusher and further reducing with the rock grinder to 2.0 or 3.0 mm size to accomodate the larger phenocrysts without excessive breakage. Approximately 20 pounds of each sample was processed in this way. Sieving was done on Tyler 8, 14, 20, 24, and 32 mesh screens. Only xenoliths and pumice fragments were retained on the 8 mesh screen. The material retained on the screens was processed with heavy liquids (bromoform and tetrabromethane diluted with ethyl alcohol) to concentrate the crystals.

The minerals from a proportionate amount of each size fraction were counted with the aid of a binocular microscope. An average of 750 grains were counted for each sample. The minerals counted were feldspar, quartz, pyroxene, and magnetite; the values are numerical amounts and do not represent volume or weight percentages.

Approximately 12.5 grams of feldspar from each of three samples were sent to Geochron Laboratories, Inc. for potassium-argon age dating. Two samples were from the Rattlesnake ignimbrite member and one was from the ignimbrite member of the Mascall.

X-ray diffraction studies were conducted on 18 feldspar samples. This was done to determine the weight percent orthoclase ($KAlSi_3O_8$) composition of the feldspar (Wright and Steward, 1968; Wright, 1968). Some samples were heated at 900 degrees Centigrade for 24 hours to produce better record quality and homogenize any exsolved phases that might be present (Tuttle, 1952; Smith, 1968).

Chemical analyses were made on a few samples to determine the percentages of the major oxides. The methods used did not allow for the determination of H_2O. Analyses for SiO_2, Al_2O_3, FeO (all iron is reported as FeO), CaO, MgO, K_2O, and TiO_2 were done by Dr. E. M. Taylor and Mr. Monty Elliott, Geology Department, Oregon State University, using X-ray emission spectroscopy. Rocky

Mountain Geochemical Corporation analyzed many samples but most of the data were questionable. Their results for Na_2O, P_2O_5, and MnO were used to augment those of Taylor and Elliott; P_2O_5 was determined colorimetrically and Na_2O and MnO were determined by atomic absorption.

Normative analyses were calculated using the "direct method" of Wahlstrom (1947).

The five-axis universal stage was used to determine optical properties on pyroxene and feldspar crystals (Emmons, 1943).

Geomagnetic polarity of field-oriented samples was read in the laboratory. This was done with a Model 70 Fluxgate Polarity Magnetometer.

A short description of the rock samples listed in Tables 1-22 is given in the Appendix. Colors were determined using the "Rock-Color Chart" (Goddard et al., 1963).

STRATIGRAPHY OF THE IGNIMBRITE SEQUENCE

General Statement

There are four Tertiary ignimbrite units in the area of this investigation. The oldest is Miocene in age and occurs in the Mascall Formation. The remaining three are Pliocene and are equivalent to the three ignimbrites of the Danforth Formation that are exposed in Devine Canyon north of Burns, Oregon on U. S. Highway 395 (Lund, 1966; Beeson, 1969). The upper ignimbrite in the Paulina Basin is equivalent to the ignimbrite member of the Rattlesnake Formation in the John Day Valley. This correlation was previously suggested by Osmont (Merriam, 1901), Chaney (1927), Wilkinson (1939), and Thayer (1952). The lower, middle, and upper ash-flow tuffs of Pliocene age in the Paulina area will hereafter be referred to, from the base upward, as crystal-rich ignimbrite, crystal-poor ignimbrite, and Rattlesnake ignimbrite.

Ignimbrite Member of the Mascall Formation

General Statement

The Mascall Formation was named by Merriam (1901) for sedimentary rocks exposed at Mascall Ranch, four miles west of Dayville, Oregon in the John Day Valley. It was described as consisting chiefly of volcanic ash and tuff with minor gravel, sand, and silt lenses. It has a total thickness of 800-1000 feet (Merriam, 1901). The fauna and flora collected from the lower part of the section in the John Day Valley have been dated as Barstovian in age. The lowermost part of the formation is intercalated with basalt flows that have been dated by potassium-argon as 15.4 million years (Evernden and James, 1964).

The ignimbrite represented on the outcrop map (Figure 3) has been assigned to the Mascall Formation of late Miocene age on the basis of its stratigraphic position, associated Barstovian mammalian fauna, and a potassium-argon age date.

In the Paulina Basin area the Mascall ignimbrite is located very near the base of the exposed Mascall section. A thin olivine basalt flow overlies the ignimbrite at a location 1-1/2 miles east of Coyote Spring (sec. 2, T. 18 S., R. 24 E.) with approximately 40 feet of tuffaceous volcanic sandstone sandwiched between them. This basalt is only locally present.

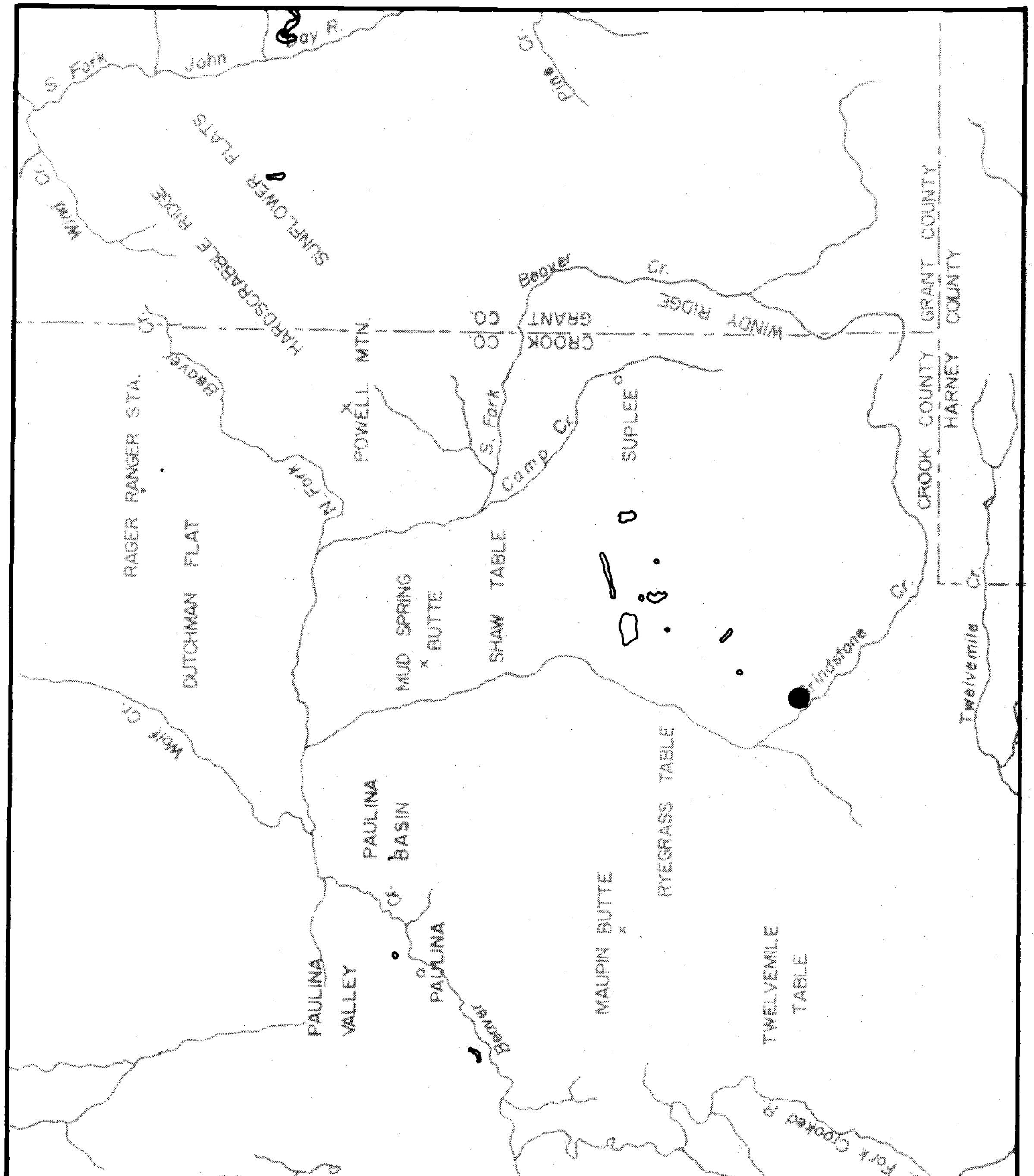
The lithology of the Mascall section seems to be similar to its correlative in the John Day Valley. The constituents are tuffaceous volcanic sandstones and conglomerates, and gravels. Forth (1965) measured a 453 feet thick Mascall section in Grindstone Canyon (NW1/4 SE1/4 sec. 9, T. 18 S., R. 24 E.) which represents the thickest exposed Mascall section within the area of investigation.

Figure 3. Outcrop map of the Mascall ignimbrite in the Paulina area.

Scale: 1/4 inch = 1 mile

ignimbrite

● Mascall fossil locality


S. Fork
John Day R.
Pine Cr.
SUNFLOWER FLATS
HARDSCRABBLE RIDGE
Wind Cr.
Beaver Cr.
GRANT CO.
CROOK CO.
WINDY RIDGE
GRANT COUNTY
CROOK COUNTY
HARNEY COUNTY
POWELL MTN.
RAGER RANGER STA.
Beaver Cr.
N. Fork
S. Fork
Camp Cr.
SUPLEE
DUTCHMAN FLAT
MUD SPRING BUTTE
SHAW TABLE
Wolf Cr.
Grindstone Cr.
Twelvemile Cr.
PAULINA BASIN
RYEGRASS TABLE
MAUPIN BUTTE
TWELVEMILE TABLE
PAULINA VALLEY
PAULINA
Beaver Cr.
S. Fork Crooked R.

The ignimbrite member of the Mascall has a limited number of exposures (Figure 3), most of which are restricted to a small basin south of Shaw Table and north of Wade Butte. Here the lower Mascall section crops out on the northwest flank of the uplifted pre-Tertiary rocks. The distribution of outcrops implies that this deposit was probably more extensive in this region at an earlier time.

Field Characteristics and Lithology

An angular unconformity exists between the Mascall ignimbrite and some of the overlying strata. This is implied rather than observed by a change in attitude between the ignimbrite and a distinctive massive tuffaceous-rich volcanic sandstone found approximately 175 feet higher in the section. The dips taken on the ignimbrite on separate fault blocks in the basin south of Shaw Table range from 5 to 25 degrees NNW. The dip of the distinctive volcanic sandstone unit in the Mascall Formation seems horizontal on the south slope of Shaw Table and in Grindstone Canyon making it concordant with the overlying crystal-rich and Rattlesnake ignimbrites.

The nuee ardente origin of the Mascall ignimbrite and the others was recognized by utilizing the criteria set forth by Enlows (1955) and Ross and Smith (1961). It is nonwelded at the base with a broad transition zone upward into a poorly welded zone; at some localities a partially welded zone occurs near the top.

The Mascall ignimbrite can be described lithologically as a vitric tuff with a small percentage of phenocrysts (Table 1). The color is commonly a light olive gray (5Y6/1) with a variation in "value" of plus or minus one. Pumice is present in some outcrops in amounts up to five percent. However, the size of the pumice lumps rarely exceed two inches and in some outcrops the predominant size is only one-fourth inch. Foreign rock fragments are found in amounts up to four percent. They are commonly one-fourth inch in diameter and rarely exceed one inch.

Table 1. Modal analyses of the Mascall ignimbrite (volume percent with voids and xenoliths excluded).

	1	2	3	4	5
Sample No.	68-1	68-2	110	111	114
Phenocrysts	2.5	2.7	1.6	0.9	1.0
Matrix	97.5	97.3	98.4	99.1	99.0
Total	100	100	100	100	100
anorthoclase	2.5	2.7	1.6	0.9	0.9
quartz	--	--	--	--	--
magnetite	tr	tr	tr	tr	0.1
clinopyroxene	--	tr	--	--	--
zircon	tr	tr	tr	tr	tr
Total	2.5	2.7	1.6	0.9	1.0
glass shards	92.3	89.3	96.9	98.5	97.5
obsidian	4.7	6.9	1.1	--	1.0
brown patches	0.5	1.1	0.4	0.6	0.5
Total	97.5	97.3	98.4	99.1	99.0
Xenoliths	2.2	3.9	2.7	3.8	1.5
Point Counts	914	1012	1289	1087	1267

In certain exposures (Figure 4) this unit bears a striking resemblance to the Rattlesnake ignimbrite and it has been mapped as such by Brogan (1952). However, on close observation small obsidian spheres or chunks are generally visible in amounts up to five percent. These are characteristic of this unit and never occur in the other ash flows.

Normal faulting in the basin south of Shaw Table has produced scarps of Mascall ignimbrite. The most noticeable scarp, 15 to 20 feet high, parallels the north side of the Paulina-Suplee road for about one mile (Figure 4). This exposure displays the prominent columnar jointing often characteristic of ash-flow tuffs (Ross and Smith, 1961).

The thickness of the Mascall ignimbrite ranges between 10 and 45 feet. At the confluence of Deer Creek and the South Fork of the John Day River the thickness is estimated to be 45 feet (Figure 5).

The dips on the Mascall ignimbrite range from 0 to 25°.

Petrography

A glass shard matrix makes up 97 to 99 percent of the Mascall ignimbrite (Table 1). The shards are brown and fresh in appearance with little noticeable alteration. The original shape of the shards is not drastically distorted as is common in more firmly welded tuffs. The lack of strong welding prevented the formation of strong eutaxitic texture so characteristic of welded tuffs (Figure 6). The shard sizes

Figure 4. Mascall ignimbrite outcrop on the south slope of Shaw Table.

Figure 5. Rattlesnake ignimbrite resting on the Mascall ignimbrite at the confluence of Deer Creek and the South Fork, John Day River.

are less than 2.0 mm. The characteristic obsidian chunks are up to 1.0 cm in diameter and their color is the same as the brown glass shards. They are found in various degrees of vesiculation. Some seem to have collapsed into a dense form after being inflated. This is indicated by a texture similar to that displayed by strongly welded tuffs.

Figure 6. Photomicrograph of the ignimbrite member of the Mascall Formation showing an obsidian chunk in a matrix of brown shards (approximately 2.4 mm x 1.6 mm).

Minerals occur as phenocrysts or microphenocrysts in the glassy matrix in amounts from 1 to 2.5 percent. They are anorthoclase and minor quartz, magnetite, zircon and rarely a green clinopyroxene. The crystals average 0.5 to 1.0 mm in diameter, occasionally reaching 3.0 mm. Most crystals are single but composites of two or three are not uncommon.

Anorthoclase crystals are euhedral to subhedral, white to colorless, and generally equidimensional to slightly elongate in shape. Some of the crystals are broken.

X-ray diffraction studies (utilizing the technique of Wright, 1968) conducted on two samples, collected 16 miles apart near the base of the unit, indicate an orthoclase content of 10 to 10.5 percent by weight (Table 2). This is a distinctly different composition than that of the feldspars in the other ash flows found in the Paulina Basin.

The anorthoclase crystals have a rind of brown glass adhering to their surface. Some of the grains have rounded corners and edges while others in close proximity display relatively sharp features. Perhaps 70 percent of the crystals show embayment features.

Albite twinning is fine to medium textured. The twin lamellae are commonly wedge-shaped. Some pericline twins occur but fine textured tartan twinning usually distinctive of anorthoclase is absent. Patchy to undulose extinction is common.

Quartz occurs infrequently and was not encountered in 5569 point counts on five thin sections. It is generally anhedral to irregular in shape, but rare subhedral to euhedral "beta" crystals do occur.

Zircon crystals are always small, seldom exceeding 0.2 mm. They are anhedral to subhedral and occur as isolated grains or

Table 2. X-ray determinations of weight % Or of alkali feldspars from the ignimbrites.

	Sample No.	Nonhomogenized	Homogenized
Rattlesnake Ignimbrite:			
Devine Canyon	182-1	?	44
S. F., John Day River	68-4	36	35
Grindstone Cr. Canyon	121-1	33.5	36
Davin Spring (middle)	147	28	36
Powell Cr. roadcut (top)	1-7	--	38.5
Powell Cr. roadcut (base)	1-2	41.5	40
Grindstone Cr. quarry (pumice)	18-L	29	30.5
S. F., Crooked River Canyon	146-1	33.5	35
Murderers Cr.	(Enlows, unpublished data)	36.5	38
Cottonwood Cr. (top)	"	26	29
Cottonwood Cr. (base)	"	31.5	33.5
Waterman Flat	"	29.5	34
Deer Cr. near Monument	"	31	--
Prairie City	"	25	32
Crystal-rich Ignimbrite:			
Devine Canyon	183-1	3.5-96	41
Beaver Creek	101-1	--	43
Mascall Ignimbrite:			
Shaw Table	110	--	10.5
S. F., John Day River	68-1	10	10

inclusions in the feldspar or magnetite.

Magnetite is an accessory mineral occurring in trace amounts in almost every thin section. Its size is similar to zircon in that the average grain is between 0.1 and 0.2 mm. The largest grain measured was 0.43 mm. Grain shapes are anhedral to euhedral with some being very irregular. It occurs as isolated grains, either single or composite, sometimes associated with zircon or inclusions in feldspar.

Clinopyroxene is the least abundant trace mineral. It is pale green, slightly pleochroic, has prismatic habit, strong birefringence, and inclined extinction.

Alteration in the Mascall ignimbrite is relatively minor. Some hematite occurs around magnetite grains but it is usually restricted to sedimentary-type xenoliths. Only one sample showed strong hematite alteration affecting the dust between the glass shards.

Devitrification is not uncommon in this unit. It may form as much as 20 percent of an individual sample but is commonly much less. The shape or boundaries of the glass shards are in no way changed by this alteration. Viewed under crossed nicols, the altered shards and obsidian chunks exhibit a yellowish color and a spherulitic extinction-cross.

Chemistry

The chemical composition of the Mascall ignimbrite member is represented in Table 3. Comparison with Nockolds' (1954) "average alkali rhyolite or rhyolite-obsidian," in the same table, shows only minor differences.

Alteration of the original composition by post-depositional leaching caused by ground water circulation is a likely probability (Lipman, 1965). Leaching tends to decrease the sodium and silicon, and increase the aluminum content. One can only speculate, in view of Lipman's (1965) conclusions, concerning the effects on the Mascall sample. No attempt was made to determine the amount of alteration the rocks have undergone in this study.

The refractive index of the shards was determined to be 1.493 (± 0.005).

Age Dating

The age of the Mascall ash flow and associated sedimentary rocks was determined by utilizing radiometric age-dating and mammalian fossils. A potassium-argon analysis on the ignimbrite yielded an age of 15.8 (± 1.4) million years. This was obtained from a sample (KA-155) collected near the confluence of Deer Creek and the South Fork of the John Day River (Figure 5).

Mammalian fossils of Barstovian age were collected from a locality in Grindstone Canyon (Figure 3). Two species of the assemblage have previously been identified as Mascall from deposits

Table 3. Chemical and normative analyses of the Mascall ignimbrite and comparisons.

	1	2	3
Sample No.	68-1*		
		Chemical Analyses (weight %)	
SiO_2	74.9	74.22	74.57
TiO_2	0.18	0.35	0.17
Al_2O_3	13.3	13.5	12.58
FeO	2.6	1.49	1.02
Fe_2O_3	--	1.09	1.30
MnO	--	--	0.05
MgO	0.5	0.19	0.11
CaO	0.6	1.03	0.61
Na_2O	3.3**	3.69	4.13
K_2O	4.30	4.33	4.73
H_2O	--	(7.39)	(0.66)
P_2O_5	--	0.11	0.07
	99.68	100	100
		Normative Analyses	
quartz	35.24		31.1
orthoclase	25.41		27.8
albite	27.90		35.1
anorthite	2.99		2.0
corundum	2.08		--
wollastonite	--		0.1
enstatite	1.25		0.3
hypersthene	4.48		0.6
apatite	--		0.2
magnetite	--		1.9
ilmenite	0.34		0.3
	99.69		99.4
Differentiation Index	89		94

(1) Mascall ignimbrite member

* Analyses by E. M. Taylor and Monty Elliott; all Fe reported as FeO, water-free.

** Analysis by Rocky Mountain Geochemical Corporation.

(2) Mascall ash (Calkins, 1902).

(3) Average rhyolite (Nockolds, 1954).

west of Paulina (Downs, 1956). The fossils from the Grindstone Canyon locality were collected as float material over a distance 45 feet above and 10 feet below a conspicuous light colored, massive tuffaceous-rich volcanic sandstone located 158 feet below the Rattlesnake ignimbrite member. This unit can be correlated with a similar exposure on the south side of Shaw Table where it crops out approximately 175 feet above the ignimbrite member of the Mascall Formation.

MASCALL FAUNAL LIST

Grindstone Canyon Assemblage +

Tephrocyon sp.
Dromomeryx borealis *
Merychippus cf. *relictus* *

+ Identifications made by Dr. J. A. Shotwell (1969, oral communication).
* Previously identified as Mascall-Crooked River assemblage by Downs (1956).

Geomagnetic Polarity

Five magnetic polarity determinations were made on hand samples from four separate outcrops of the Mascall ignimbrite. Some of these were separated by as much as 16 miles. Two samples collected south of Shaw Table (sec. 25, T. 17 S., R. 24 E.) gave determinations that were weakly "normal." This is in accord with a rhyolite tuff near Twelve Mile Creek in which the magnetic polarity is also "normal" and the age is 15.81 (±0.40) million years (Dalrymple et al., 1967). The polarity of the remaining three samples was too weak to measure with the available equipment.

Pliocene Ignimbrites

Stratigraphic Nomenclature

The Rattlesnake ignimbrite member is a time-rock-stratigraphic unit. It was originally described as a distinct lithologic member within the Rattlesnake Formation by Merriam (1901). There is now sufficient evidence to extend this unit beyond the boundaries of the Rattlesnake Formation into the Harney Basin where it is included in the Danforth Formation. In the northwest part of the Harney Basin

> the upper part of the Danforth Formation comprises stratified siltstone, sandstone, tuff and volcanic ash with a few intercalated layers of glassy rhyolite and one distinctive rhyolite tuff-breccia member [Rattlesnake ignimbrite].

The formation is named for the Danforth Ranch, T. 22 S., R. 32-1/2 E., along Cow Creek (Piper, Robinson and Park, 1939).

It seems necessary to adopt a nomenclature suitable for an equivalent time-rock-stratigraphic unit found in two widely separated formations of completely different lithologies. Therefore, it is suggested that it be referred to as the ignimbrite member of the Rattlesnake Formation in the John Day Valley and the Rattlesnake ignimbrite member of the Danforth Formation in the Paulina Basin and Harney Basin. It is also suggested that the strata from the base of the crystal-rich ignimbrite to the base of the Ochoco basalt in the Paulina area be assigned to the Danforth Formation (Plate 1). This would exclude the use of the term "Rattlesnake Formation" for strata south of the Ochoco Uplift that are correlative but have different lithologies.

A brief survey of the three Pliocene ash-flow tuffs indicates the lower one, or crystal-rich ignimbrite member and the upper, or Rattlesnake ignimbrite member, are quite extensive in the area of this investigation. In contrast, the middle crystal-poor ignimbrite occurs only in the southeast corner of the area (Plate 1).

All three units are vitric tuffs but there are enough differences in their lithologies to make them distinctive. The crystal-rich ignimbrite member is conspicuously lacking in pumice while the phenocryst content is commonly five percent or greater. The crystal-poor ignimbrite member is very dense, strongly welded, devitrified, and no pumice or phenocrysts are noted. The Rattlesnake ignimbrite member is conspicuously pumiceous and its crystal content is approximately one percent.

The ages of the above ignimbrite units have been determined by radiometric age dates and Hemphillian mammalian fauna collected from associated sedimentary rocks.

Crystal-Rich Member of the Danforth Formation

General Statement

This ash flow is assigned to the middle Pliocene on the basis of an age date of 9.2 million years obtained from an exposure on the South Fork of the Crooked River (Walker, 1969, oral communication). This unit can be traced north along the South Fork, Crooked River Canyon (Figure 7) to Bill Jake Hollow (Plate 1) where is is covered by the overlying rocks. It crops out again five miles north along Beaver Creek just south of the hamlet of Paulina. This ash flow and the tuffaceous deposits between it and the upper ignimbrite had previously been assigned to the Mascall Formation by Forth (1965). In view of the age date of 9.2 million years obtained on the crystal-rich ignimbrite and Hemphillian mammalian fossils collected from the sedimentary rocks above this unit, it is suggested that the Mio-Pliocene boundary be placed at the base of the crystal-rich ash flow. The possibility of earlier Pliocene sedimentary rocks occurring below this arbitrary boundary is suggested by Walker, Peterson and Greene (1967), but supporting evidence is lacking.

A correlation between the crystal-rich ignimbrite occurring on the South Fork of the Crooked River and the lower ignimbrite of the Danforth Formation in the Harney Basin has been suggested by Walker (oral communication, 1969). This is based on similar lithologies and several radiometric dates over a vast region.

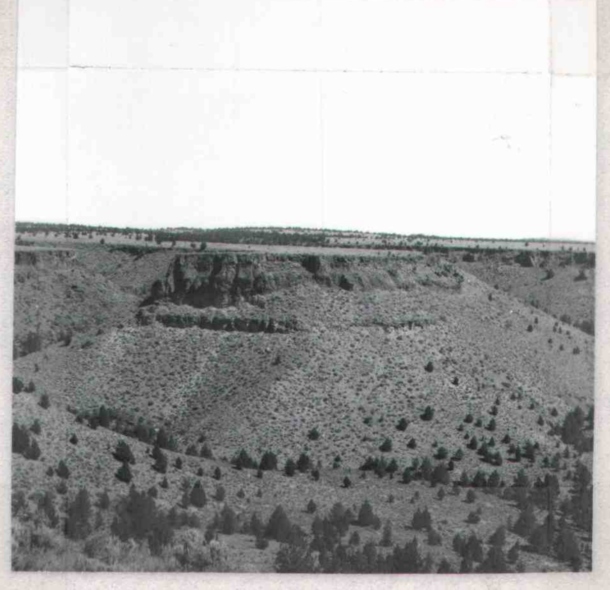


Figure 7. Outcrop of the crystal-rich ignimbrite underlying a thick section of Rattlesnake ignimbrite in the South Fork, Crooked River Canyon.

Field Characteristics

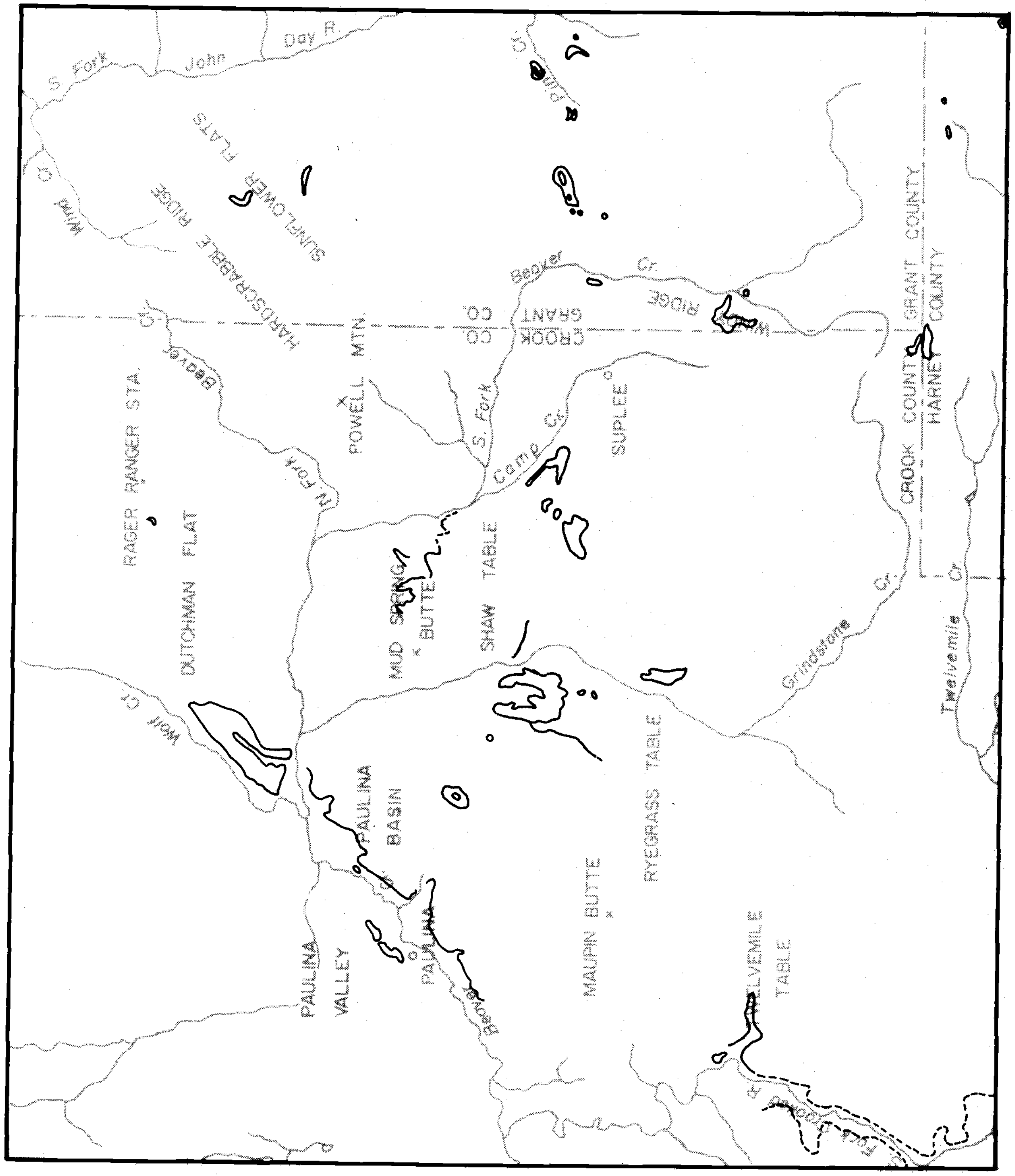
The crystal-rich ignimbrite is a simple cooling unit that appears to have covered most of the lowland area in this region (Figure 8). At many localities erosion has formed escarpments or benches where the ignimbrite is intercalated between soft tuffaceous sedimentary rocks. A notable example is the lower bench near Beaver Creek, south and east of Paulina.

The escarpments provide a means for observing the gross physical properties of the unit. All outcrops exhibit a jointing pattern of some type. The most common is columnar. Other types observed

Figure 8. Outcrop map of the crystal-rich ignimbrite in the Paulina area.

Scale: 1/4 inch = 1 mile

ignimbrite



S. Fork
John
Day R.
Wind Cr.
SUNFLOWER FLATS
HARDSCRABBLE RIDGE
Beaver
Cr.
RIDGE
GRANT CO.
CROOK CO.
POWELL MTN.
Beaver Cr.
RAGER RANGER STA.
N. Fork
S. Fork
Camp Cr.
SUPLEE
GRANT COUNTY
HARNEY COUNTY
CROOK COUNTY
DUTCHMAN FLAT
MUD SPRING BUTTE
SHAW TABLE
Grindstone Cr.
Wolf Cr.
Twelvemile Cr.
PAULINA BASIN
RYEGRASS TABLE
MAUPIN BUTTE
PAULINA
PAULINA VALLEY
TABLE

were platy, blocky, and spheroidal in decreasing order of importance. The latter are restricted to the zone of dense welding, whereas columnar jointing commonly extends down through the zone of partial welding.

At many outcrops the lower zone of no welding or poor welding is covered by talus. The majority show a rather thick zone of vitrophyre and a much thinner zone of partial welding. Only the dense vitrophyre is commonly observed in the southeast part of the area. The upper partially welded and non welded zones have presumably been stripped-off by erosion.

The thickness ranges between 10 and 45 feet. The thickest section is to be found near Bill Jake Hollow (Plate 1) on the South Fork of the Crooked River. The attitude of the unit varies between 0 and 6°.

The lithology is as distinctive as the name "crystal-rich" implies. Its color is typically light olive gray (5Y6/1) but light gray (N7) or brownish gray (5YR6/1) is not unusual. The upper part is commonly oxidized to a pale red (5Y6/2). At a rock quarry one mile east of the Sartain Ranch the contact between the oxidized and unoxidized rock is as sharp as a penciled line. The phenocryst content ranges between 1 and 23 percent and the xenoliths are on the order of 1-2 percent. Foreign rock fragments of a sedimentary nature commonly form limonitic spots up to one-fourth inch in diameter. These are most apparent in the poorly to moderately welded rocks. Basalt fragments up to three inches across have been observed but are rare. Pumice fragments are conspicuously absent except at a few outcrops where they contribute up to 2 percent of the rock. These fragments have a maximum diameter of one-half inch.

Petrography

The matrix material makes up 75 to 97 percent of the rock. It is composed of colorless glass shards which exhibit a maximum diameter of 1.0 mm and an average diameter of 0.2 to 0.3 mm (Figure 9). There is a small amount of interstitial volcanic dust between the shards.

Foreign rock fragments are commonly volcanic sandstones, sandy siltstones, siltstones, and a rare arenite. Volcanic xenoliths of basaltic and rhyolitic types make up less than one-half of the total.

The phenocryst content appears to increase upward from the basal nonwelded zone. One exposure in particular, located near Bill Jake Hollow, has a notable increase in crystal content from approximately 1 percent at the base to about 15 percent near the top of a 43 foot thick section. The maximum crystal size also tends to increase as one proceeds from bottom to top. In one vertical section the maximum grain size increases from 0.55 mm to 1.4 mm and in another an increase from 0.75 mm to 2.5 mm was noted.

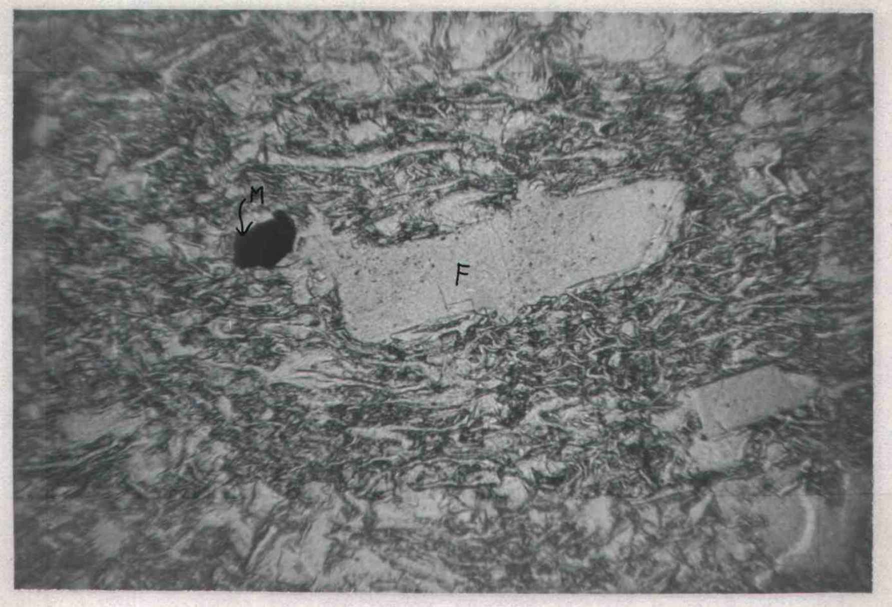


Figure 9. Photomicrograph of the crystal-rich member of the Danforth Formation showing feldspar (F) and magnetite (M) grains in a fine textured colorless shard matrix (approximately 2.4 mm x 1.6 mm).

The modal analyses in Table 4 illustrate a wide variation in the phenocryst content ranging from 1 to 23 percent. It is noted that even though the ratio of feldspar to quartz is not consistent, the mineralogy is similar. The principal minerals are alkali feldspar and quartz; magnetite, zircon and clinopyroxene occur only in trace amounts.

Alkali feldspars make up the majority of the phenocrysts. They have a maximum diameter of 3.5 mm and average about 1.0 mm. Crystals are usually single but composites are not uncommon. Most grains are subhedral to anhedral and many not only are cracked or fractured but exhibit embayment features.

Table 4. Modal analyses of the crystal-rich ignimbrite (volume percent with void and xenoliths excluded).

	1	2	3	4	5	6	7	8	9
Sample No.	1-1	8	149	101-2	180-2	0-23	0-29	0-30	4-21-2
Matrix	98.9	94.7	82.4	97.6	89.3	77.8	95.3	80.5	77.0
Phenocrysts	1.1	5.3	17.6	2.4	10.7	22.2	4.7	19.5	23.0
Total	100	100	100	100	100	100	100	100	100
feldspar	1.0	4.0	11.0	2.0	8.5	14.5	2.4	10.0	13.0
quartz	0.1	1.1	6.5	0.4	2.0	7.7	2.3	9.5	10.0
magnetite	tr	0.1	tr	tr	0.2				
pyroxene	--	0.1	0.1	--	tr				
zircon	--	--	--	tr	--				
Xenoliths	2.2	2.2	0.2	1.5	1.8	0.9	tr	0.1	1.0
Point counts	1462	1439	1357	1362	960				

(1), (2), (3) and (4) Paulina area.

(5) Devine Canyon, north of Burns, Oregon.

(6) After Beeson (1969); north of Burns on U. S. Highway 395.

(7) After Beeson (1969); near Silvies, Oregon.

(8) After Beeson (1969); 30 km east of Silvies, Oregon.

(9) After Beeson (1969); sec. 5, T. 20 S., R. 28 E., Sawtooth Creek Quadrangle, Oregon.

The feldspar composition for one sample was determined by X-ray diffraction to be 43 percent orthoclase by weight (Table 2). This sample was collected from a basal poorly welded zone. The individual crystals probably vary from this value although no studies have been made to determine exactly how much. The data suggests the feldspars are soda-sanidine.

The optic angles are consistently greater than 15 degrees and it is estimated that many are near 30 degrees. Two optic angles obtained by universal stage determination methods were 33 and 39°. Twinning is not common; tartan twinned crystals occurred in only one thin section indicating the presence of anorthoclase.

Quartz crystals form up to 6.5 percent of the rock. They are anhedral to subhedral with very few euhedral "beta" forms. The size ranges from small fragments up to grains 2.0 mm in diameter. They are commonly cracked, fractured and embayed.

Magnetite occurs as small anhedral to euhedral crystals, usually less than 0.3 mm in diameter, and as irregular patches. The crystals form isolated grains in the glassy matrix or inclusions in the other phenocrysts.

Clinopyroxene grains are green, anhedral to euhedral, and usually less than 1.0 mm in diameter. The optic sign is positive, interference colors are second order green-yellow, pleochroism is slight to nonexistent, and the extinction angles are 30 to 40°. The refractive index for alpha (1.735) and gamma (1.768) was determined on one grain. The data suggests the pryoxene is an iron-rich augite or aegirine-augite.

Alteration of the pyroxene is not common but it does occur along the margin of some crystals. Alteration products are chlorite, green hornblende (?), and biotite.

Chemistry

A sample of this unit collected one mile south of Paulina was chemically analyzed. The results shown in Table 5 indicate a rhyolitic composition. Greene (1970) reports the average silica content of the devitrified tuff is 75 percent and the sodium and potassium oxides each amount to approximately four percent. The potassium in the Paulina sample is about two percent lower and the silica is three percent higher than the averages reported by Greene (1970). Beeson's (1969) single analysis from Devine Canyon is close to that of Greene's.

The single analysis from the Paulina area cannot be taken as representative of the unit. The chemical variation from Greene's and Beeson's analyses might be explained by inhomogeneity in the distribution of phenocrysts.

The refractive index for the glass from the chemically analyzed sample is 1.490 (± 0.005).

Table 5. Chemical and normative analyses of the crystal-rich ignimbrite member.

	1	2
Sample No.	101*	4-21-2
	Chemical Analyses (weight %)	
SiO_2	78.4	75.27
TiO_2	0.20	0.28
Al_2O_3	12.5	13.63
FeO	3.0	1.07
Fe_2O_3	--	1.00
MnO	--	0.03
MgO	0.4	0.08
CaO	0.6	0.30
Na_2O	2.8**	3.14
K_2O	1.84	5.20
H_2O	--	(2.90)
P_2O_5	--	--
	99.74	100
	Normative Analyses	
quartz	50.87	33.88
orthoclase	10.87	31.15
albite	23.67	28.64
anorthite	2.99	1.51
corundum	4.78	2.54
wollastonite	--	--
enstatite	1.00	0.23
hypersthene	5.18	0.59
apatite	--	--
magnetite	--	1.06
ilmenite	0.38	0.39
	99.74	99.99
Differentiation Index	85	94

(1) Paulina Basin sample.

* Analyses by E. M. Taylor and Monty Elliott, all Fe reported as FeO, water-free.

** Analysis by Rocky Mountain Geochemical Corporation.

(2) Devine Canyon sample; data after Beeson (1969); recalculated water-free.

Geomagnetic Polarity

Magnetic polarity determinations were made on 11 samples of the crystal-rich ignimbrite member. Nine of the samples were collected from various widely separated exposures in the Paulina area, two were collected in Devine Canyon. The samples consistently gave "normal" polarity readings although some were very weak. The polarity could not be determined for two samples.

The polarity and potassium-argon age date of 9.2 million years (Walker, 1969, oral communication) are consistent with the results of Dalrymple et al. (1967). They reported a "normal" polarity for a rhyolitic welded tuff in the Drewsey Formation (T. 20 S., R. 36 E., Burns, Oregon Quadrangle) that has an age of 9.15 (± 0.19) million years. A previous date of 8.9 million years was published for this unit from the same locality (Evernden et al., 1964).

Source

Greene (1970) suggests the source for the crystal-rich ignimbrite is in the "northwest corner of the Harney Basin lowland." This is supported by an isopach map of the unit that indicates a maximum thickness of over 100 feet in the Silvies River and Devine Canyon area north of Burns, Oregon (Greene, 1970). This ash flow once covered approximately 7000 square miles in southeast Oregon with an average thickness of 35 feet and had a volume of probably 45 cubic miles (Walker, 1970; Greene, 1970).

Crystal-Poor Ignimbrite Member of the Danforth Formation

The unit is middle Pliocene in age. It is the least extensive of the four ignimbrites in the mapped area (Figure 10) but extends southward into the Harney Basin where it is believed to be widespread. The exposures in the thesis area are restricted to those near Snow Mountain (Plate 1). One is on top of Big Mowich Mountain and the other is about three miles southeast near Pendleton Spring. It occurs between the crystal-rich and Rattlesnake ignimbrite members. The outcrops are located in a densely forested area that contains few good exposures. Therefore, the thickness could not be determined accurately.

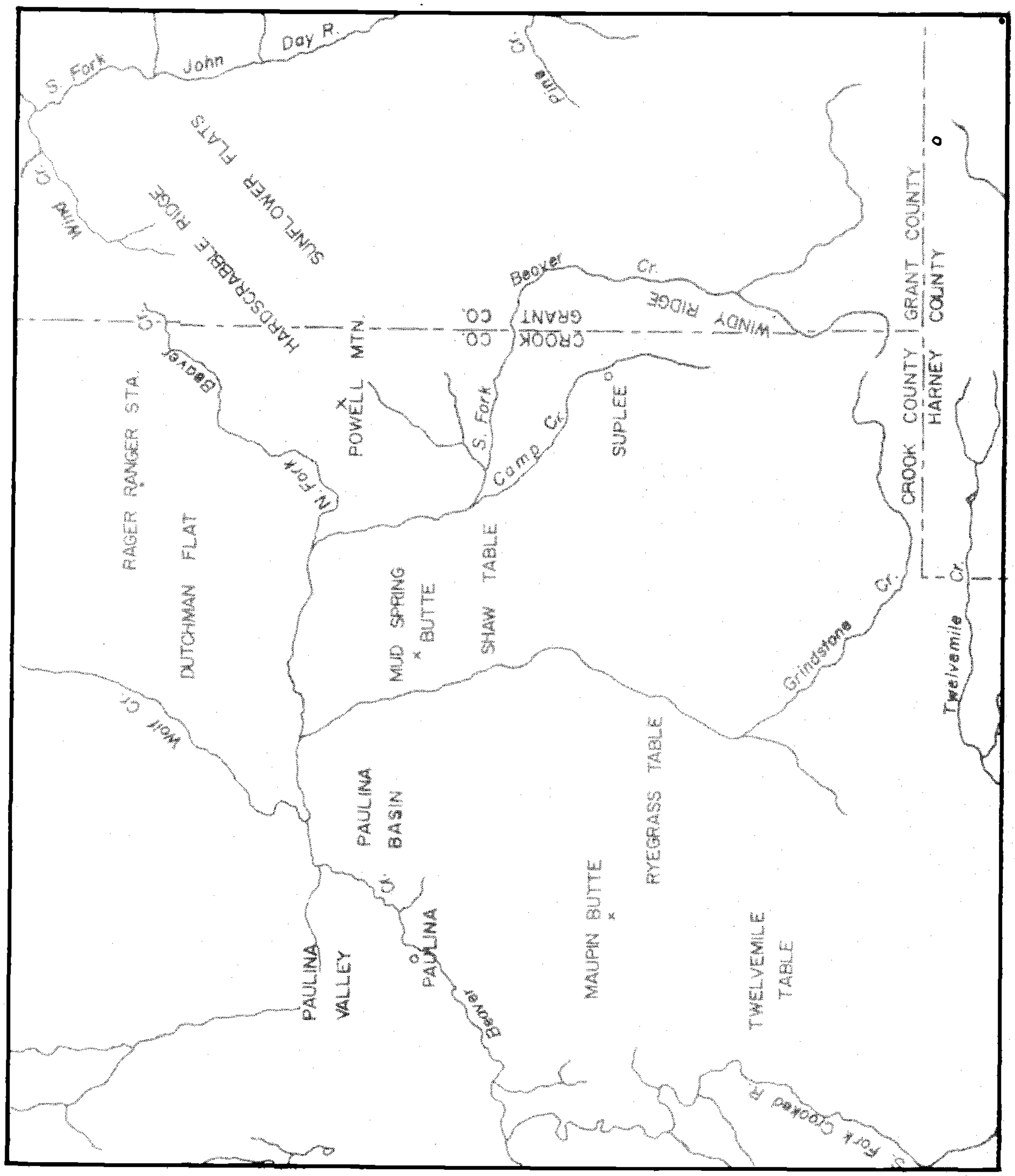
The crystal-poor ignimbrite member in this area is equivalent to the middle Danforth ignimbrite member exposed in Devine Canyon (Beeson, 1969). This correlation is based on its stratigraphic position, relative age, lithology, and petrography.

The crystal-poor ignimbrite member is light gray (N7), dense, devitrified, strongly welded, and has a few gas cavities up to one-eighth inch in diameter and a very few microphenocrysts and pumice fragments. The lithology is the same in Devine Canyon but the gas cavities are considerably larger.

Figure 10. Outcrop map of crystal-poor ignimbrite in the Paulina area.

Scale: 1/4 inch = 1 mile

ignimbrite


S. Fork John Day R.
Pine Cr.
SUNFLOWER FLATS
HARDSCRABBLE RIDGE
Wind Cr.
Beaver Cr.
WINDY RIDGE
GRANT CO.
CROOK CO.
GRANT COUNTY
CROOK COUNTY
HARNEY COUNTY
POWELL MTN.
S. Fork
Camp Cr.
SUPLEE
RAGER RANGER STA.
Beaver Cr.
N. Fork
DUTCHMAN FLAT
MUD SPRING BUTTE
SHAW TABLE
Grindstone Cr.
Twelvemile Cr.
Wolf Cr.
PAULINA BASIN
RYEGRASS TABLE
MAUPIN BUTTE
TWELVEMILE TABLE
PAULINA VALLEY
PAULINA
Beaver Cr.
Crooked R.
S. Fork Crooked R.

The microphenocrysts occur as fragments of alkali feldspar and quartz in amounts considerably less than one percent (Table 6). They are fractured, anhedral, and have a maximum diameter of 0.25 mm.

Table 6. Modal analyses of the crystal-poor ignimbrite member (volume percent with voids and xenoliths excluded).

	1	2
Sample No.	150	181-1
Matrix	100	99.9
Phenocrysts	tr	0.1
Total	100	100
alkali feldspar	tr	0.05
quartz	tr	0.05
Xenoliths	0.6	0.1
Point Counts	1414	1339

A faint vitroclastic texture is discernible although most of the original shard boundaries have been destroyed by subsequent devitrification (?) (Figure 11). A mosaic texture is common although some very small axiolites are present. An X-ray diffraction record of a whole rock sample indicates the presence of quartz and alkali feldspar with only minor cristobalite. Previous X-ray analyses of devitrified Tertiary rocks proved cristobalite and feldspar the major constituents (Ross and Smith, 1961). The cristobalite in this unit has either inverted to quartz or the ignimbrite was hot enough for primary crystallization. The thick zones of dense welding and devitrification and the lack of phenocrysts suggest the latter.

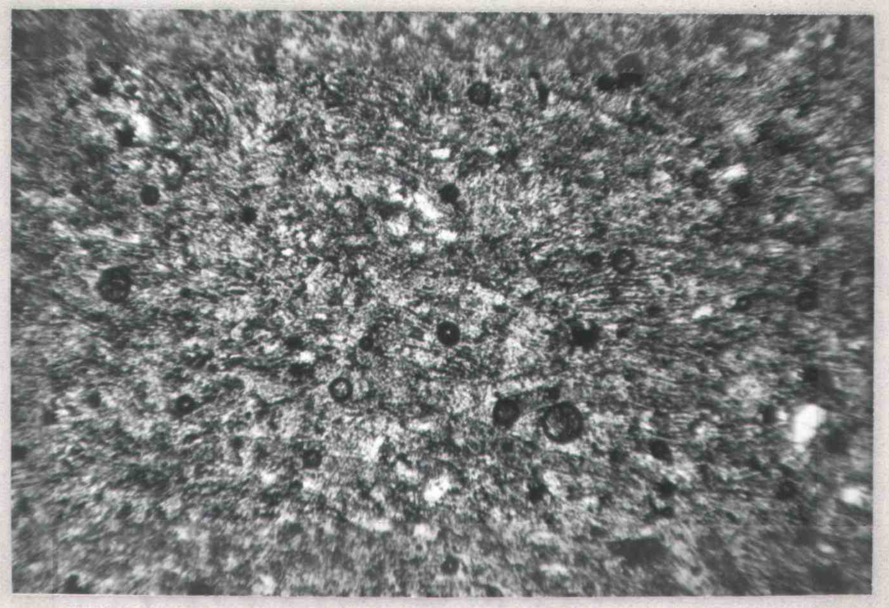


Figure 11. Photomicrograph of the crystal-poor ignimbrite member of the Danforth Formation showing a microcryptocrystalline groundmass where only slight vestiges of the shard boundaries remain (approximately 2.4 mm x 1.6 mm).

The chemical composition of the crystal-poor ignimbrite exposed at Pendleton Spring was determined and is presented in Table 7. The results are similar to the "average alkali rhyolite and rhyolite-obsidian" of Nockolds (1954). A comparison of the samples in Table 7 shows a striking similarity between the crystal-poor ignimbrite from Pendleton Spring and the middle ash-flow tuff of the Danforth Formation from Devine Canyon. The refractive index of the devitrified glass is 1.487 (± 0.005).

The magnetic polarity was not determined from Pendleton

Table 7. Chemical and normative analyses of the crystal-poor ignimbrite member.

	1	2
Sample No.	150*	0-20-2
	Chemical Analyses (weight %)	
SiO_2	75.6	75.24
TiO_2	0.10	0.18
Al_2O_3	12.3	13.91
FeO	2.6	0.31
Fe_2O_3	--	1.54
MnO	--	0.01
MgO	0.2	0.16
CaO	0.2	0.14
Na_2O	4.5**	4.07
K_2O	4.45	4.43
H_2O	--	(1.23)
P_2O_5	--	0.01
	99.95	100
	Normative Analyses	
quartz	29.84	31.82
orthoclase	26.30	26.36
albite	38.05	36.85
anorthite	0.09	0.64
corundum	--	2.40
wollastonite	0.38	--
enstatite	0.50	0.45
hypersthene	4.61	--
apatite	--	0.02
magnetite	--	0.33
ilmenite	0.19	0.26
hematite	--	0.89
	99.96	99.99
Differentiation Index	94	95

(1) Near Pendleton Spring.

* Analyses by E. M. Taylor and Monty Elliott; all Fe reported as FeO, water-free.

** Analysis by Rocky Mountain Geochemical Corporation.

(2) Data after Beeson (1969); middle ash-flow tuff of Danforth Formation; sample location on Highway 395 north of Burns; analysis recalculated water-free.

Spring for lack of an oriented sample. A weakly "normal" polarity determination was made on a sample from Devine Canyon, but two other samples from the same area gave no reading.

Rattlesnake Ignimbrite Member of the Danforth Formation

General Statement

The Rattlesnake ignimbrite member is believed to be a single ash-flow unit that covered most of the Harney Basin and extended northward into the Crooked River region and the John Day Valley as far north as Monument, Oregon. This unit is a member of the Rattlesnake Formation in the John Day Valley (Merriam, 1901). In the Harney Basin it is a part of the Danforth Formation (Piper, Robinson and Park, 1939), and of late has been referred to as the upper ignimbrite member of the Danforth Formation (Lund, 1966; Beeson, 1969; Walker, 1969, oral communication).

Distribution and Thickness in Area of Study

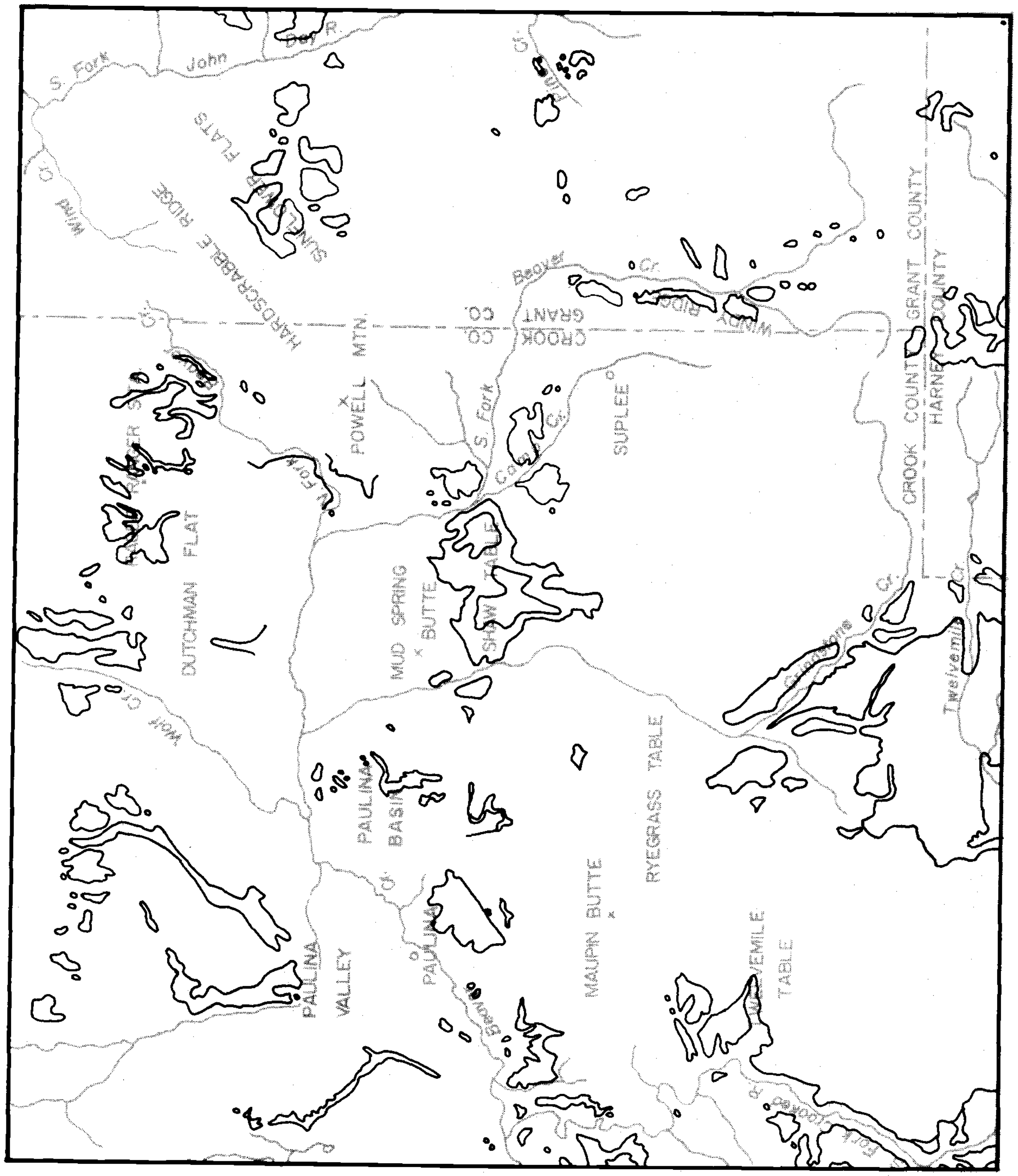
The Rattlesnake ash flow is believed to have covered approximately 90 percent (600 square miles) of the area studied by the author. The outcrop map in Figure 12 indicates a present exposure of approximately 75 square miles.

The thickness was controlled to a large degree by the topography

Figure 12. Outcrop map of the Rattlesnake ignimbrite in the Paulina area.

Scale: 1/4 inch = 1 mile

 ignimbrite



S. Fork
John
Wind Cr.
FLATS
HARDSCRABBLE RIDGE
Beaver
Cr.
Windy Ridge
GRANT CO.
CROOK CO.
POWELL MTN.
S. Fork
Cr.
SUPLEE
DUTCHMAN FLAT
MUD SPRING BUTTE
SHOW
CROOK COUNTY
GRANT COUNTY
HARNEY COUNTY
Wolf Cr.
PAULINA
BASIN
RYEGRASS TABLE
MAUPIN BUTTE
PAULINA
VALLEY
PAULINA
TABLE
Cr.

at the time of deposition. The isopach map in Figure 13 was constructed from 46 measured sections. The values do not represent the original thickness; they do indicate the thickness of the erosional remnants. The map does, however, given an indication of the depositional thickening and thinning of the ash-flow sheet. The average thickness is approximately 30 feet. The maximum thickness is 110 feet along the South Fork of the Crooked River (Figure 7).

Unconformities

The Rattlesnake ignimbrite member rests with angular unconformity on pre-Tertiary rocks in the southeast part of the area; it lies with disconformity on the Mascall Formation. In many places the Rattlesnake ignimbrite member rests with disconformity on the crystal-rich ignimbrite member but an angular unconformity seems to occur locally (sec. 21, T. 17 S., R. 25 E.).

The Ochoco Basalt of Pliocene age rests with angular unconformity on the Rattlesnake ignimbrite member on the east side of Dutchman Flat (sec. 9, T. 16 S., R. 25 E.) but at most places it is disconformable.

Field Characteristics

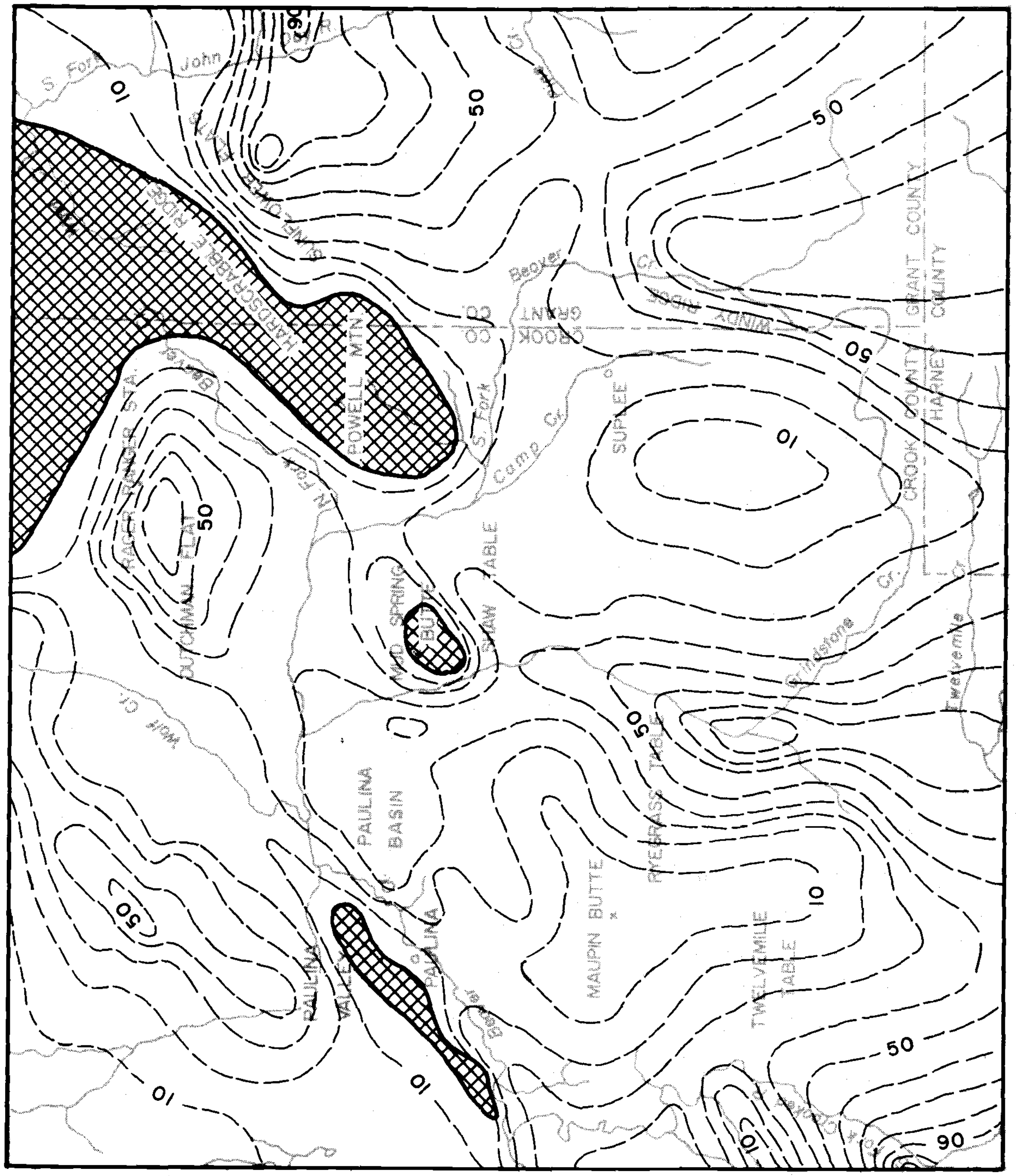
The once extensive ash-flow sheet has been eroded to form isolated flat-topped remnants. These form spectacular tablelands

Figure 13. Isopach map of Rattlesnake ignimbrite constructed from 46 measured sections.

Scale: 1/4 inch = 1 mile

probable highland area of nondeposition

—10— contour interval 10 feet



POWELL MTN
HARDSCRABBLE RIDGE
DUTCHMAN FLAT
MUD SPRING BUTTE
SHAW TABLE
SUPLEE
PAULINA BASIN
MAUPIN BUTTE
TWELVEMILE TABLE
PAULINA VALLEY
PAULINA
WINDY RIDGE
CROOK CO
GRANT CO
CROOK COUNTY
GRANT COUNTY
HARNEY COUNTY
Beaver Cr.
Camp Cr.
S. Fork
Grindstone Cr.
Twelvemile Cr.
Wolf Cr.
10
50
90

throughout this region and have their greatest development along the Crooked River, Beaver, Grindstone, and Paulina Creeks (Figure 14). Ryegrass Table, Twelvemile Table, and Dutchman Flat are surfaced with younger Ochoco basalt flows and not the Rattlesnake ignimbrite member as might be suspected from a distance.

Figure 14. Tablelands capped by the Rattlesnake ignimbrite in the Paulina Basin, 1 mile east of Paulina.

Many tablelands are the erosional results of the resistant ignimbrite resting on soft, friable rocks. In the region where the ignimbrite overlies more resistant strata, i.e., Columbia River Basalt or the pre-Tertiary complex, its prominent appearance is substantially reduced.

The dips on the Rattlesnake ignimbrite are generally low, ranging from 0 to 6° in the northwestern part of the area. The ash flow overlying the Mesozoic and Paleozoic rocks to the southeast have dips that are more erratic. They do not have a preferred direction and the greatest dip is 26°. This is a result of the isolated remnants of the Rattlesnake ignimbrite conforming to adjustments along faults in the pre-Tertiary complex. There are a number of faults in the Tertiary sequence that displace the ignimbrite in amounts up to 250 feet, but most are less than 100 feet.

The Rattlesnake ignimbrite is folded into two synclines. One is the Old Cabin syncline (Dickinson and Vigrass, 1965) located south of Pine Creek (Plate 1, sec. 19, T. 17 S., R. 27 E.). The dip of the ignimbrite is 26°W. on the eastern limb of the fold. The other syncline is located between Grindstone Creek and Beaver Creek with the axis trending approximately N. 45°E. (Plate 1). The limbs of the fold dip inward about 2-3°. The axial area of this structure contains the thickest section of post-Rattlesnake ignimbrite sedimentary rocks exposed in this region.

Jointing

Columnar jointing is present at almost all exposures. It is not present in the basal nonwelded tuff but is exhibited in the more firmly-welded zones. It has been observed that the jointing becomes more close-set as the welding increases. Vertical joints are the normal type but at one location in Bill Jake Hollow closely spaced columnar jointing is warped from the vertical as much as 25°.

Platy jointing is commonly found near the uppermost part of the unit where it is probably enhanced by weathering along the eutaxitic structure. Intense platy jointing is common where devitrification occurs in the densely welded zone (Figure 15). In the southeastern part of the area along Beaver Creek the jointing is so closely spaced that exposures have the appearance of a breccia.

Figure 15. Closely-spaced platy jointing in the dense, devitrified zone of the Rattlesnake ignimbrite in Grindstone Canyon (6 inch rule for scale).

The density of the jointing is directly responsible for the size of debris found on the talus slopes below the erosional escarpments.

In moderately welded terrane, blocks of tuff 10 feet in diameter are commonly found lying at the base of the cliffs or on the slopes below. In contrast, the intensely jointed, dense, devitrified welded tuff may be covered with a scree of angular fragments 1 inch in diameter or less.

Welding

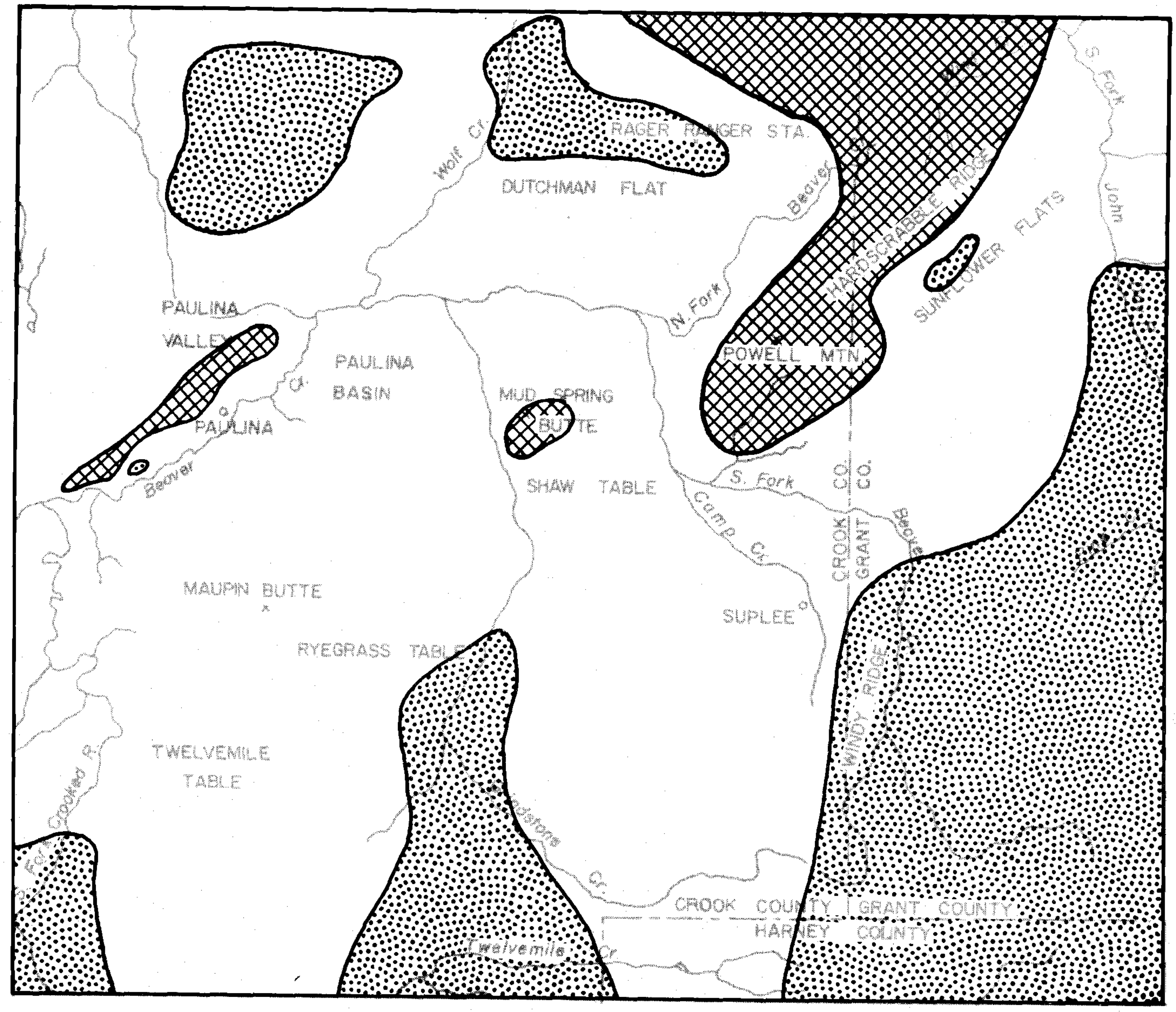
The factors that influence welding in ash-flow tuffs are: (1) thickness, (2) initial heat, (3) volatiles, and (4) dispersal (Ross and Smith, 1961). Many field observations establish that the thicker the unit the more intense the welding. The map in Figure 16 shows the areas where dense welding occurs. These correspond to the areas where the ignimbrite is the thickest (Figure 13). The thickest zone of dense welding, 60 feet, was measured in the South Fork of the Crooked River Canyon (Figure 7). This is also the thickest ignimbrite section.

In reference to the zones of welding it seems appropriate to use the terminology set forth by Smith (1960a). Two to three zones are recognized in most outcrops of the Rattlesnake ignimbrite member. They are the lower zones of no welding and partial welding and the zone of dense welding. Because of erosion rarely was there an upper partially welded zone and never an upper zone of no welding. The part of the ash-flow sheet deposited over and on the flanks of highland areas was thin and commonly did not develop a complete zonation

Figure 16. Distribution map of the zone of dense welding in the Rattlesnake ignimbrite.

Zone of dense welding

Highland area of nondeposition


RAGER RANGER STA.
DUTCHMAN FLAT
Wolf Cr.
Beaver
N. Fork
HARDSCRABBLE RIDGE
SUNFLOWER FLATS
S. Fork
John
POWELL MTN.
PAULINA VALLEY
PAULINA BASIN
PAULINA
Beaver
MUD SPRING BUTTE
SHAW TABLE
S. Fork
Camp Cr.
CROOK CO.
GRANT CO.
SUPLEE
MAUPIN BUTTE
RYEGRASS TABLE
TWELVEMILE TABLE
WINDY RIDGE
Crooked R.
Cr.
CROOK COUNTY
GRANT COUNTY
HARNEY COUNTY
Twelvemile Cr.

sequence.

Figure 17 shows a rather rapid transition from the basal zone of no welding through a thin partially welded zone to the zone of dense welding over a vertical interval of about 2-1/2 feet. Other outcrops show the transition to be considerably more gradual and extend over a thicker interval.

In most exposures the eutaxitic texture is very prominent. It results from the partial or complete collapse of pumice fragments (Figure 18). As welding and gaseous activity increased in the upper density welded zone, devitrification produced a more uniform appearance to the rock.

Devitrification and Vapor-Phase Mineralization

Devitrification and vapor-phase mineralization are the post-depositional changes that produce crystalline material during and after the cooling of the ash flow (Ross and Smith, 1961). Devitrification is moderate to strong within the areas of dense welding (Figure 16). Recognizable vapor phase mineralization on the outcrop is rare.

Devitrification can be recognized on the outcrop by a change in the rock from a glassy to a dull luster. This change is not a transitional one but is very sharp. In Grindstone Canyon weathering along this contact has produced a straight horizontal niche on the face of a precipitous cliff that is so marked it was first thought to represent

Figure 17. Abrupt transition from the nonwelded to the densely welded zone in the Rattlesnake ignimbrite; roadcut near Powell Creek (6 inch rule for scale).

Figure 18. Partially welded Rattlesnake ignimbrite with abundant pumice, location southwest of Davin Spring (hammer for scale).

the contact between two ash flows (Figure 19). Ratté and Steven (1967) report a similar sharp contact in the Wason Park Rhyolite, San Juan Mountains, Col. separating the vitrophyric zone from the devitrified zone. The Rattlesnake ignimbrite member in the South Fork, Crooked River Canyon (Figure 7) exhibits strong devitrification not only in the strongly welded zone but also in the lower partially welded zone. The contact of the devitrified and glassy tuff is sharp, but irregular. There are isolated patches of devitrified and glassy tuff both above and below the contact.

A few thick, densely welded rocks contain cavities formed by vapor pressure during welding (Figure 20). These cavities are commonly elongated, parallel to the eutaxitic texture and locally reach 15 inches in length. The cavities are restricted to the densely welded devitrified zones.

Vapor-phase mineralization appears to be absent in most outcrops of the Rattlesnake ignimbrite but it was recognized on Powell Creek. The upper 10 feet of a 45 foot vuggy section have lenticular drusy cavities lined with small vapor-phase crystals. The cavities normally several inches long are here no more than an inch in diameter and the normally homogeneously colored rock is here mottled with shades of tan, yellow, brown and maroon.

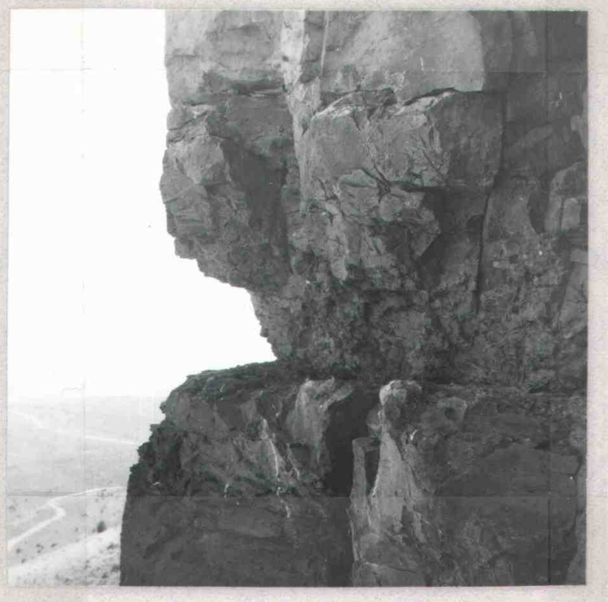


Figure 19. Niche on face of Rattlesnake ignimbrite cliff marks contact between dense glassy zone and upper devitrified zone in Grindstone Canyon (niche about 1 foot high).

Figure 20. Gas cavities in the dense, devitrified zone of the Rattlesnake ignimbrite along Powell Creek (hammer for scale).

Lithology

The Rattlesnake ignimbrite is a pumiceous vitric tuff. Pumice fragments are one of the distinguishing characteristics of the unit. Most are white, some are black, and others are banded black and white or shades of gray or brown. The largest pumice fragments were observed in the lower nonwelded or poorly welded zones. The maximum pumice size is 15 inches but clasts 6 inches or less are far more common. The amount of pumice in the rock ranges from 1 to 30 percent. Most exposures contain an average of 5 percent at the base.

The ignimbrite is poor in phenocrysts, generally containing about one percent. Most of the crystals are colorless and less than 2. 0 mm in diameter. The small size inhibits an accurate identification in hand specimen but the cleavage surfaces on most indicate feldspar.

Foreign rock fragments are predominantly basalt and varicolored cherts, with lesser amounts of sandstone and siltstone. The maximum size of the clasts measured was 10 inches but at most exposures the largest clasts were not over 2-1/2 inches long. Fragments other than basalt do not exceed 1 inch. The larger fragments occur near the base of the unit. It must be noted that with the increase in welding the rock color darkens upward in the section, thus making the xenoliths more difficult to distinguish on the outcrop surface.

The color of the ignimbrite is not consistent and changes with welding, devitrification, and oxidation. The basal nonwelded to poorly welded zones are light gray (N7), yellowish gray (5Y7/2), light olive gray (5Y6/1), or very pale orange (10YR8/2). The adjacent partially welded zone is light to medium light gray (N6, N7), light olive gray (5Y6/1) or some shade of orange or yellowish brown. The dense glassy zone is darker, with grays ranging from light to medium (N5 to N7) and locally olive gray (5Y5/1, 5Y4/1) or yellowish olive gray (5Y6/2). The dense devitrified zone is commonly a pinkish gray (5YR8/1), to a light brownish gray (5YR6/1), or a pinkish red (10R7/2). Where the upper partially welded tuff occurs it is a light gray (N7), yellowish to olive gray (5Y7/1, 5Y7/2), grayish pink (5R8/2), or a pale red (5R6/2). It is common for the upper part of the unit to be oxidized to a pink or reddish color.

Many of the partially welded rocks have a speckled appearance that is noticeable only on close observation. The specks or small spots are thought to be the result of iron diffusion into the matrix from small xenoliths or from brownish patches of an unknown material.

Petrography

Modal analyses of the Rattlesnake ignimbrite member from the Paulina Basin area are given in Tables 8-15. The phenocryst

Table 8. Modal analyses of a Rattlesnake ignimbrite section on Pine Creek (volume percent with voids and xenoliths excluded).

	1	2	3	4	5
Sample No.	63-1	63-2	63-3	63-4	63-5
Position	base				top
Matrix	98.8	99.4	99.0	98.6	98.8
Phenocrysts	1.2	0.6	1.0	1.4	1.2
Total	100	100	100	100	100
colorless glass	22.1	23.3	--	--	--
brown glass	74.7	--	--	--	--
devitrified and vapor-phase minerals	0.3	75.6	98.8	98.3	96.8
brown patches	1.7	0.5	0.2	0.2	2.0
alkali feldspar	1.2	0.6	0.9	1.2	1.1
quartz	tr	tr	tr	0.2	0.1
magnetite	tr	tr	0.1	tr	tr
pyroxene	--	tr	tr	tr	tr
zircon	tr	--	tr	--	--
Xenoliths	3.0	2.0	0.6	1.1	1.2
Point counts	976	1259	1365	1313	1399

Table 9. Modal analyses of a Rattlesnake ignimbrite section in Grindstone Canyon (volume percent with voids and xenoliths excluded).

	1	2	3	4
Sample No.	121-2	121-3	121-4	121-5
Position	base			top
Matrix	99.0	99.0	98.6	99.2
Phenocrysts	1.0	1.0	1.4	0.8
Total	100	100	100	100
colorless glass	39.2	36.8	--	--
brown glass	59.3	58.3	--	--
divitrified and vapor-phase minerals	--	1.0	97.3	98.5
brown patches	0.5	1.9	1.3	0.7
alkali feldspar	0.6	0.7	1.2	0.5
quartz	0.4	0.1	--	0.1
magnetite	tr	0.1	0.2	tr
pyroxene	tr	0.1	tr	0.2
zircon	--	--	--	tr
Xenoliths	0.5	2.8	0.6	2.0
Point counts	1280	1504	1395	1376

Table 10. Modal analyses of a Rattlesnake ignimbrite section in a roadcut near Powell Creek (volume percent with voids and xenoliths excluded)

	1	2	3	4	5	6
Sample No.	1-2	1-3	1-4	1-5	1-6	1-7
Position	base					top
Matrix	99.6	99.4	99.4	99.0	99.3	99.6
Phenocrysts	0.4	0.6	0.6	1.0	0.7	0.4
Total	100	100	100	100	100	100
colorless glass	99.6	89.0	28.1	--	--	--
brown glass	--	10.3	71.1	--	--	--
devitrified and vapor-phase minerals	--	--	--	99.0	99.0	96.8
brown patches	--	0.1	0.2	--	0.3	2.8
alkali feldspar	0.2	0.6	0.5	1.0	0.6	tr
quartz	0.1	tr	0.1	tr	0.1	0.1
magnetite	0.1	tr	tr	tr	tr	0.3
pyroxene	tr	tr	tr	--	tr	--
zircon	tr	tr	--	tr	--	tr
Xenoliths	0.6	0.5	1.3	1.4	0.8	1.0
Point counts	1194	1353	1311	1376	1458	1208

Table 11. Modal analyses of a Rattlesnake ignimbrite section in the South Fork, Crooked River Canyon (volume percent with voids and xenoliths excluded).

	1	2	3	4
Sample No.	146-2	146-3	146-4	146-5
Position	base			top
Matrix	98.8	99.6	98.7	98.9
Phenocrysts	1.2	0.4	1.3	1.1
Total	100	100	100	100
colorless glass	--	--	--	--
brown glass	--	--	--	--
devitrified and vapor-phase minerals	97.8	98.7	97.3	98.1
brown patches	1.0	0.9	1.4	0.8
alkali feldspar	0.8	0.4	0.9	0.7
quartz	0.4	tr	0.1	tr
magnetite	tr	tr	0.3	0.4
pyroxene	tr	--	tr	tr
zircon	tr	--	--	--
Xenoliths	0.6	4.8	0.6	5.8
Point counts	1252	1378	1444	1492

Table 12. Modal analyses of a Rattlesnake ignimbrite section one mile east of Dry Paulina Creek (volume percent with voids and xenoliths excluded)

	1	2	3	4	5	6
Sample No.	26-1	26-2	26-3	26-4	26-5	26-6
Position	base					top
Matrix	100	99.2	98.3	98.8	99.8	99.4
Phenocrysts	tr	0.8	1.7	1.2	0.2	0.6
Total	100	100	100	100	100	100
colorless glass	25.6	24.7	--	--	--	26.4
brown glass	68.3	46.9	--	--	--	64.3
devitrified and vapor-phase minerals	--	--	97.5	96.5	97.5	0.2
brown patches	6.1	27.6	0.8	2.4	2.3	8.5
alkali feldspar	--	0.8	0.6	0.8	tr	0.5
quartz	--	--	--	0.2	0.1	--
magnetite	tr	--	1.1	0.2	0.1	0.1
zircon	--	--	--	tr	--	--
Xenoliths	0.3	0.1	0.4	0.4	--	1.2
Point counts	1314	795	1321	1563	1256	1278

Table 13. Modal analyses of a Rattlesnake ignimbrite section at the confluence of Deer Creek and the South Fork, John Day River (volume percent with voids and xenoliths excluded).

	1	2	3
Sample No.	68-4	68-5	68-6
Position	base		top
Matrix	98.8	99.1	99.2
Phenocrysts	1.2	0.9	0.8
Total	100	100	100
colorless glass	57.4	47.8	44.2
brown glass	40.1	50.7	51.0
devitrified and vapor-phase minerals	--	--	2.6
brown patches	1.3	0.6	1.4
alkali feldspar	1.2	0.6	0.8
quartz	--	0.3	--
magnetite	tr	tr	0.1
pyroxene	tr	tr	tr
zircon	--	tr	tr
Xenoliths	1.2	0.3	1.7
Point counts	1159	940	1340

Table 14. Modal analysis of the Rattlesnake ignimbrite 1/4 mile west-southwest of Davin Spring (volume percent with voids and xenoliths excluded).

Sample No.	147
Position	middle
Matrix	99.7
Phenocrysts	0.3
Total	100
colorless glass	25.0
brown glass	74.4
devitrified and vapor-phase minerals	--
brown patches	0.3
alkali feldspar	0.3
quartz	tr
magnetite	tr
pyroxene	--
zircon	tr
Xenoliths	1.2
Point counts	1282

Table 15. Modal analyses of the Rattlesnake ignimbrite member near Pendleton Spring (volume percent with voids and xenoliths excluded).

	1	2	3
Sample No.	151-1	151-2	151-3
Position	float	float	float
Matrix	98.7	98.9	99.2
Phenocrysts	1.3	1.1	0.8
Total	100	100	100
colorless glass	35.6	33.0	--
brown glass	62.8	65.7	--
devitrified and vapor-phase minerals	--	0.2	96.6
brown patches	0.3	--	2.6
alkali feldspar	1.1	0.9	0.9
quartz	0.1	0.2	0.1
magnetite	0.1	tr	tr
pyroxene	tr	tr	0.1
zircon	tr	tr	tr
Xenoliths	0.5	0.5	0.5
Point counts	1490	1314	1420

content is approximately 1 percent and the xenoliths are slightly higher. A vitroclastic matrix accounts for the remainder.

The matrix consists of glass shards and dust, irregular patches of a brown isotropic unknown material, and small silky, fibrous or vesicular textured pumice fragments. The shards are less than 3.0 mm and most are less than 1.5 mm. The gross texture in the nonwelded to partially welded rock is similar to that of the Mascall ignimbrite and both are notably coarser than the crystal-rich unit (Figure 21).

Figure 21. Photomicrograph of the Rattlesnake ignimbrite member showing a relatively coarse texture, poor welding, brown and colorless shards (approximately 2.4 mm x 1.6 mm).

A microscopically visible eutaxitic texture is superimposed on the readily discernible vitroclastic texture when welding and compaction occur. The shards become increasingly flattened, elongated in the horizontal, and warped around the phenocrysts and foreign rock fragments. Welding and compaction result in a decrease in the porosity and an increase in the density of the tuff.

The most distinctive petrographic characteristic of the Rattlesnake ignimbrite is the occurrence of both brown and colorless shards (Figure 21). Ignoring color differences, they look much the same with the exception of size, the brown being the smaller of the two. Beeson (1969) also noticed that the brown shards are on the average slightly smaller than the colorless ones.

Thin sections show color variations between shards from colorless to light tan to brown. There are also color variations within individual shards. Some brown shards have a thin colorless rind. The rind does not appear to be the result of devitrification as in a similar instance discussed by Ross and Smith (1961).

Point counting of the two shard types indicates a change in their ratio as one ascends vertically in the section. Tables 10, 13, and 15 show an increase in brown glass upward in the section. This upward increase is also supported by modal analyses from Cottonwood Creek, Waterman Flat, and Murderers Creek sections (Tables 16-18). Devitrification in the upper part destroys the original color of

Table 16. Modal analyses of a Rattlesnake ignimbrite section on Cottonwood Creek in the John Day Valley (volume percent with voids and xenoliths excluded).

	1	2	3	4
Sample No.	E-3-65	E-4-65	E-5-65	E-6-65
Position	base			top
Matrix	98.5	98.4	96.3	99.0
Phenocrysts	1.5	1.6	3.7	1.0
Total	100	100	100	100
colorless glass	97.7	98.0	54.6	73.0
brown glass	--	--	40.8	24.3
devitrified and vapor-phase minerals	--	--	--	--
brown patches	0.8	0.4	0.9	1.7
alkali feldspar	1.1	1.4	1.3	0.8
quartz	0.3	--	--	tr
magnetite	0.1	0.1	1.9	0.2
pyroxene	tr	0.1	0.5	--
zircon	--	tr	--	tr
Xenoliths	2.8	1.3	5.1	2.0
Point counts	668	1409	397	798

Table 17. Modal analyses of a Rattlesnake ignimbrite section near Waterman Flat west of the John Day Valley (volume percent with voids and xenoliths excluded).

	1	2	3
Sample No.	E-45-67	E-45-67	E-45-67
Position	base	middle	top
Matrix	100	99.1	99.5
Phenocrysts	tr	0.9	0.5
Total	100	100	100
colorless glass	93.6	39.8	20.9
brown glass	--	57.0	70.8
devitrified and vapor-phase minerals	--	--	0.2
brown patches	6.4	2.3	7.6
alkali feldspar	tr	0.8	0.3
quartz	tr	0.1	0.1
magnetite	tr	tr	0.1
pyroxene	--	tr	--
zircon	--	--	tr
Xenoliths	0.2	2.4	1.5
Point counts	1332	1423	1405

Table 18. Modal analyses of a Rattlesnake ignimbrite section on Murderers Creek (volume percent with voids and xenoliths excluded).

	1	2	3
Sample No.	E-84-67	E-85-67	E-86-67
Position	base		top
Matrix	99.8	98.9	99.4
Phenocrysts	0.2	1.1	0.6
Total	100	100	100
colorless glass	84.3	23.2	--
brown glass	--	70.2	--
devitrified and vapor-phase minerals	--	--	97.9
brown patches	15.5	5.5	1.5
alkali feldspar	0.2	0.3	0.3
quartz	tr	0.6	tr
magnetite	tr	0.2	tr
pyroxene	--	tr	tr
zircon	--	--	--
Xenoliths	4.5	0.9	2.5
Point counts	795	1431	1510

Table 19. Modal analysis of the Rattlesnake ignimbrite near Prairie City (volume percent with voids and xenoliths excluded).

Sample No.	E-71-67
Matrix	99.6
Phenocrysts	0.4
Total	100
colorless glass	97.8
brown glass	--
devitrified and vapor-phase minerals	--
brown patches	1.8
alkali feldspar	0.4
quartz	tr
magnetite	--
pyroxene	--
zircon	--
Xenoliths	--
Point counts	949

Table 20. Modal analyses of the Rattlesnake ignimbrite member of the Danforth Formation in Devine Canyon (volume percent with voids and xenoliths excluded).

	1	2	3	4	5
Sample No.	182-2	182-3	182-4	182-5	182-6
Position	base				top
Matrix	99.4	98.7	99.2	99.2	99.5
Phenocrysts	0.6	1.3	0.8	0.8	0.5
Total	100	100	100	100	100
colorless glass	43.8	28.0	--	--	98.6
brown glass	55.3	23.6	--	--	--
devitrified and vapor-phase minerals	--	46.6	97.6	97.2	--
brown patches	0.3	0.5	1.6	2.0	0.9
alkali feldspar	0.5	1.0	0.3	0.5	0.3
quartz	0.1	0.1	0.4	0.1	0.1
magnetite	tr	0.1	0.1	0.2	tr
pyroxene	tr	0.1	--	tr	0.1
zircon	--	--	--	tr	--
Xenoliths	0.2	tr	tr	0.3	tr
Point counts	1299	1192	1073	1452	1493

the shards. Many exposures of the basal tuff contain no brown glass.

Mineralogy

The mineral suite determined from 159 thin sections consists of alkali feldspar, quartz, clinopyroxene, magnetite, and zircon. An average phenocryst content of 0.9 percent was obtained with 41,806 point counts on 32 representative thin section.

The histograms in Figure 22 represent mineral percentages made by grain counts with the binocular microscope. These are not weight or volume percentages but merely represent the number of grains counted. If weight or volume were considered, magnetite would show a much lower percentage because of its small size. Each histogram from the Paulina Basin area shows a similar relationship. Feldspar is always the major mineral with subordinate quartz, magnetite, and pyroxene occurring in that order.

The feldspar-to-quartz averages for the John Day Valley (Enlows, unpublished data), Paulina Basin, and one analysis from Devine Canyon are also given in Figure 22. The Paulina Basin and Devine Canyon samples match perfectly, but there is a discrepancy with the John Day Valley histogram. Reasons for the differences can probably be attributed to a combination of the following:

(1) different investigators processing the different samples, errors in quartz and feldspar recognition have shown up on

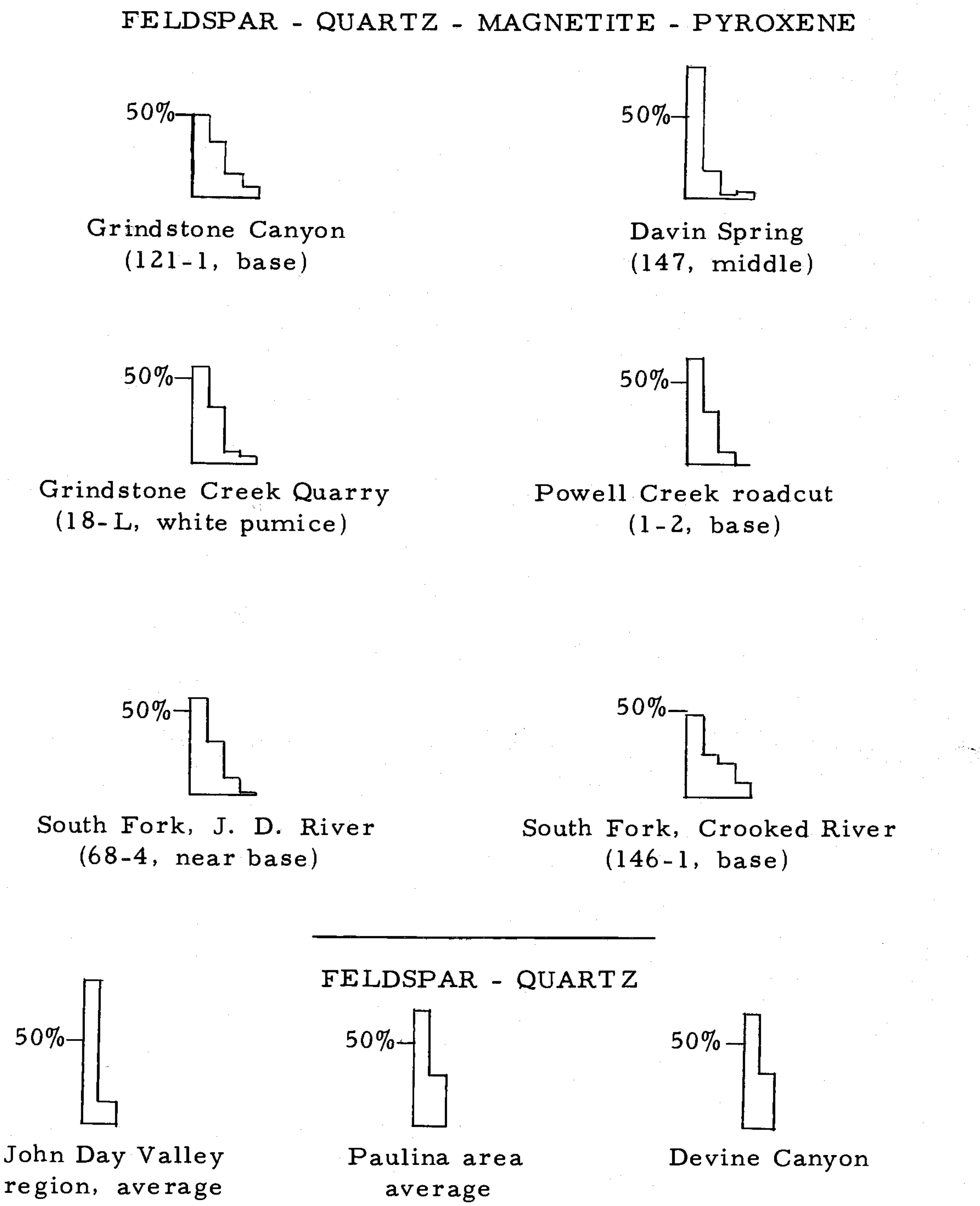


Figure 22. Histograms of Rattlesnake Ignimbrite mineral percentages (represents grain counts and not volume or weight percent).

the diffraction patterns on 9 of the 12 samples from all three areas;

(2) inherent differences in the unit.

Point counting with the petrographic microscope of thin sections produced the following results:

	Quartz	Feldspar	Point Counts
John Day Valley Region	14%	86%	83
Paulina Area	10	90	316
Devine Canyon	24	76	42

Feldspar. Anorthoclase was identified by the distinctive fine-textured tartan twinning and the soda-sanidine by the lack of twinning and by X-ray diffraction techniques. The optic angles were estimated to range between 20 and 50°.

Universal stage measurements on four grains gave the following results:

2V(°)
45
42
39
33

X-ray determinations on the feldspars from various locations also indicated anorthoclase and soda-sanidine (Table 2). An average composition of 33.5 percent orthoclase by weight was determined for the nonhomogenized samples from the Paulina area. An average of

30 percent Or was obtained for the samples north of the Ochocos. The feldspars from the Rattlesnake ignimbrite member are a high temperature variety between high sanidine and high albite (Figure 23).

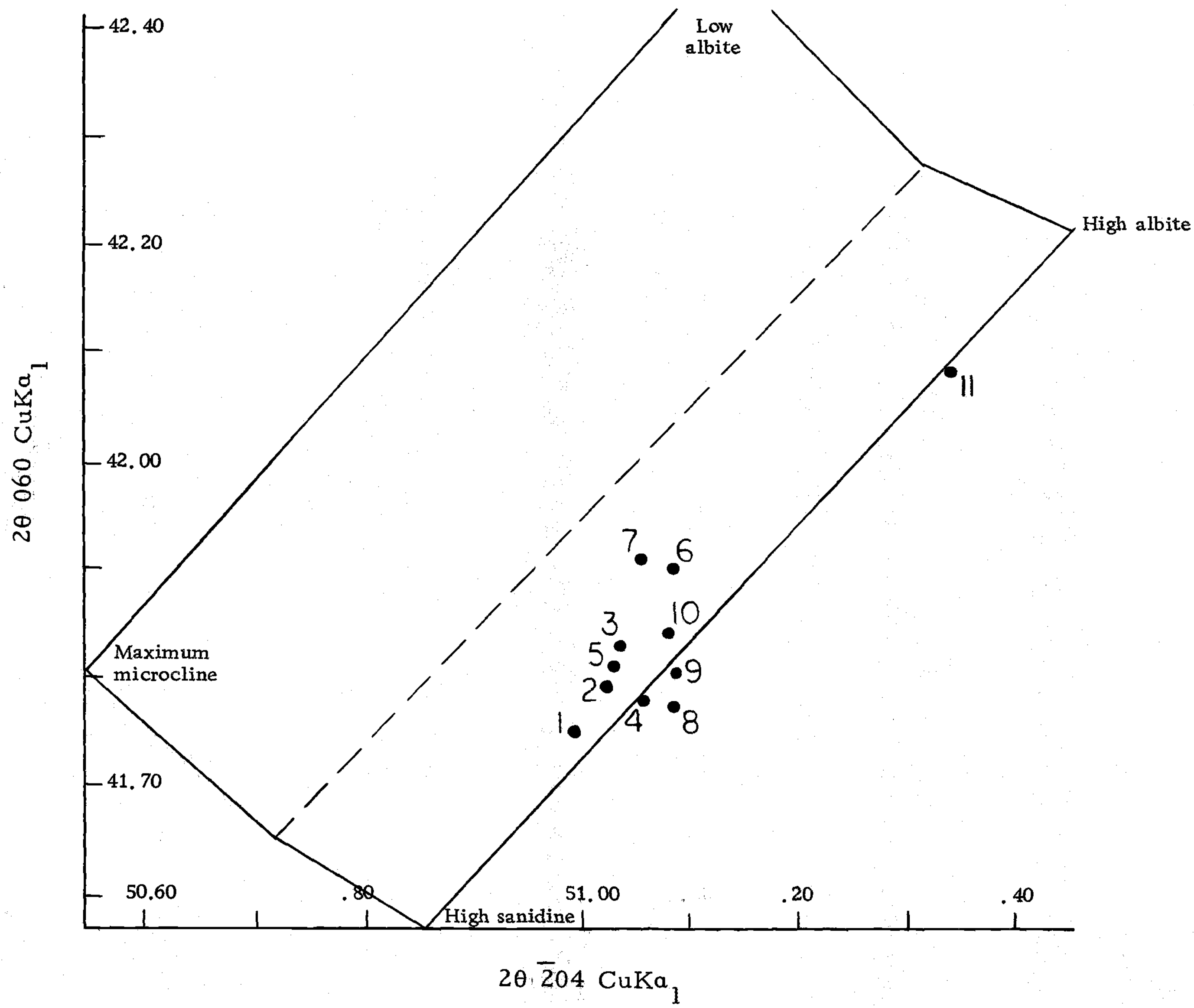
The majority of crystals are subhedral but there are variations from anhedral to euhedral. The maximum grain diameter for most phenocrysts in thin section is 2.0 mm, rarely they approach 4.0 mm. The average is 1.0 mm. Some grains show embayment features while others show no resorption despite their close proximity to each other. Many crystals are fractured and cracked. Patchy extinction is common. The feldspars are of fresh appearance, showing no signs of clay alteration.

Quartz. This is the second most abundant mineral. It occurs as anhedral to euhedral crystals, often embayed, cracked and fractured. The euhedral ones are a "beta"-quartz dipyramidal form. Some contain inclusions of magnetite; others are composites with other quartz or feldspar grains. Although some grains exceed 1.0 mm in diameter, most are smaller.

Magnetite. The grains of magnetite are considerably smaller than the quartz or feldspar; none exceed 1.0 mm in diameter, and the average is less than 0.25 mm. The grains are euhedral to anhedral. Some magnetite seems to be deuteric, forming irregular patches molded between the glass shards. Solitary crystals commonly occur as inclusions in feldspar, pyroxene, and rarely quartz. Ninety-three

Figure 23. Plot of the structural state of the ignimbrite feldspars utilizing the ($\overline{2}04$) and (060) 2θ peak positions (after Wright, 1968).

1	Rattlesnake	- Roadcut near Powell Creek
2	Crystal-rich	- Devine Canyon
3	Rattlesnake	- South Fork, John Day River
4	Rattlesnake	- South Fork, Crooked River
5	Rattlesnake	- Grindstone Canyon
6	Rattlesnake	- Davin Spring
7	Rattlesnake	- Cottonwood Creek
8	Rattlesnake	- Murderers Creek
9	Rattlesnake	- Waterman Flat
10	Rattlesnake	- Grindstone Creek
11	Mascall	- South side of Shaw Table


Low albite
High albite
Maximum microcline
High sanidine
42.40
42.20
42.00
41.70
50.60
.80
51.00
.20
.40
2θ 060 CuKα1
2θ $\bar{2}$04 CuKα1
1
2
3
4
5
6
7
8
9
10
11

percent of the thin sections contained at least one grain of magnetite.

Most of the magnetite remains unaltered except for grains near the top of the ignimbrite. These are often oxidized either partly or completely to hematite.

Clinopyroxene. A green clinopyroxene is one of the least abundant minerals in the suite. It occurs in 60 percent of the thin sections with a frequency of 1 to 3 grains per section. The grain size ranges from 0.2 mm to 1.0 mm in diameter and there is an assortment of shapes. The pyroxenes studied under the binocular microscope from the disaggregated basal tuffs are very elongate in the c direction. They have a splintery appearance with crude but recognizable crystal forms. The pyroxenes are generally studded with magnetite grains.

The color is light to moderate green and some grains show weak to moderate pleochroism from green to yellowish-green. The optic sign is positive and the optic angles were estimated to be 45 to 55°. The extinction angles average 36°. The five-axis universal stage was used to determine the 2V and extinction angles of a few grains. These were taken on separate pyroxene grains; the asterisk indicates the most reliable 2V angle results (see page 80).

The maximum interference color is second order green-yellow. Twinning is rare but a few twins were observed.

2V (°)	Extinction (°)
64 ?	44
64 *	42
58 *	41
56	36 ?
55	33
48	31
47 *	
42	

The indices of refraction for alpha and gamma were determined on several pyroxenes derived from different locations. The values for the crystals do not vary more than (±) 0.001. The results are given below:

alpha = 1.726
gamma = 1.758
birefringence = 0.032

The optical properties indicate the clinopyroxene is probably an iron-rich augite (Deer, Howie and Zussman, 1963, vol. 2). The extinction angles are generally too high and the optic axial angles too low to be aegirine-augite.

Only a few grains were observed that had altered to hornblende or chlorite around their edges. The remaining grains were fresh. At the Powell Creek roadcut (Plate 1) the pyroxenes in the nonwelded basal tuff were bleached to a canary yellow color.

Zircon. Microphenocrysts of zircon form isolated grains in the matrix or inclusions in feldspar, pyroxene or magnetite. They seem to have a particular affinity for magnetite. Anhedral to euhedral in shape, their size can be described as minute, rarely exceeding a diameter of 0.25 mm. At least one zircon crystal was observed in 34 percent of the thin sections.

Xenoliths

The lithics, like the phenocrysts, make up a minor part of the rock. The average amount computed from Tables 8-15 is only 1.2 percent. If we consider those rock fragments too large to be counted in a thin section but observable on outcrop, this figure might reach 3 percent. The xenoliths can be grouped into four basic types: sedimentary rocks 71%, silicic volcanic rocks 21%, mafic volcanic rocks 7%, quartzite 1% (percentages determined from thin sections). The sedimentary rocks consist of volcanic sandstones, tuffaceous volcanic sandstones, and siltstones. The larger lithic fragments, i.e., those larger than one-half inch, are predominantly basalt. Chert fragments are included in the silicic volcanic rocks because of the difficulty in distinguishing the two.

Alteration

The major alterations involve devitrification of the glass and oxidation of the iron minerals. Iron alteration in the form of hematite or limonite is present in 67 percent of the thin sections. The constituents most affected by this alteration are the foreign rock fragments, brown patches of an unknown material, and magnetite. Where the upper portion of the unit is a reddish color, the volcanic dust between the shards has also altered to hematite. Most of the alteration is considered mild.

Only a few occurrences of saponite (?) were observed. This mineral filled small cavities and fractures in the glassy matrix and feldspar crystals.

Chlorite and hornblende form rims around a small percentage of the green pyroxene grains, but only three or four grains show these products. Three samples have calcite present in very minute grains and all three were collected from the porous basal zone of the unit, suggesting that the calcite was probably deposited by circulating ground water.

The basal nonwelded and partially welded zones and the upper partially welded zone generally have minor amounts of devitrification. This occurs as yellowish brown shards that exhibit a spherulitic type extinction when the nicols are crossed. Axiolitic textures are the rule in the strongly devitrified zone. The collapsed pumice has a distinctly coarser axiolitic texture than the shards. Higher in the section porosity increases and the centers of the larger elongate axiolites are hollow, allowing for the formation of vapor-phase minerals. In some instances devitrification produced a fine mosaic texture in the shards but the vitroclastic texture is discernible and in no case completely destroyed. An X-ray diffraction pattern of a devitrified rock indicates the major products are a fine-grained intergrowth of cristobalite and feldspar.

A few spherulites were observed in thin section but never in hand sample. The spherulitic zone described by Lund (1966) in the upper ignimbrite member of the Danforth Formation in Devine Canyon is not present in the Paulina Basin area.

Where vapor phase mineralization occurred it is almost always restricted to the upper part of the ash flow where the minerals are deposited in small cavities. The shapes of the gas cavities are irregular to lenticular and locally are partly or completely filled with alkali feldspar, cristobalite and tridymite. The cavities are usually rimmed with coarse axiolites but the radial structure is not large enough to be seen with the naked eye.

Petrographic Similarities

F. C. Calkins (1902) was the first investigator to report on the petrography of the Rattlesnake Formation from the John Day Valley. He refers to the ignimbrite in the following:

> The coarse tuff occurring near the middle of the section is a porous, light gray rock, composed of angular lapilli, with rather numerous grains of feldspar, and comparatively few of quartz and green augite.

Later referring to the feldspars he describes them as mainly "anorthoclase." The author supports the early work of Calkins adding magnetite and zircon to his mineral suite.

The mineralogy of the ignimbrite member in the John Day Valley region is identical to that in the Paulina area. A comparison of the modal analyses presented in Tables 8-20 fully supports this conclusion. Modal analyses averages are listed below:

Modal Analyses Averages of the Rattlesnake Ignimbrite		
	Matrix	Phenocrysts
Devine Canyon	99.2%	0.8%
Paulina area	99.1	0.9
John Day Valley region	99.0	1.0

The feldspar compositions determined for weight percent orthoclase by X-ray diffraction are presented in Table 2. The values differ by a small amount but there seems to be a systematic decrease in the orthoclase content from Devine Canyon to the John Day Valley region.

Average Weight % Orthoclase	
Devine Canyon	44 (homogenized)
Paulina area	33.5
John Day Valley region	30

An important characteristic of the Rattlesnake ignimbrite is the hybrid glass shards. Both the brown and the colorless shards occur throughout the ignimbrite sheet with the exception of the Prairie City area where the brown shards seem to be absent.

Walker (1969) described the upper Danforth ash flow in the Buzzard Creek area as a crystal-poor unit with 98 percent hybrid matrix composed of colorless and pinkish or yellowish brown shards having an index of about 1.500 (±.005). He also describes a mineralogy similar to the Rattlesnake, i.e., the major minerals are sanidine, quartz, green clinopyroxene, and plagioclase. Accessory minerals were listed as magnetite, colorless clinopyroxene and oxyhornblende. The oxyhornblende was never observed in the Rattlesnake ignimbrite to the north, but the plagioclase and colorless augite are believed cognate minerals of the black pumice. Thayer (1952) reported xenocrysts of plagioclase and olivine in the Rattlesnake ignimbrite from the John Day Valley, but these could also be phenocrysts from the black pumice.

Black and Banded Pumice

The majority of pumice in the Rattlesnake ignimbrite member in the Paulina area is white, fibrous, silky, or vesicular in texture. Additionally, a conspicuous black and a banded variety (Figure 24) occurs in lesser amounts; the two pumice types are not recognized at every outcrop.

Figure 24. Banded pumice fragment from the Rattlesnake ignimbrite member collected in a quarry west of Grindstone Creek.

Black pumice clots up to 10 inches in diameter are found in the poorly welded basal zone. Although the black pumice seems to be absent at some outcrops it has invariably been recognized in thin section. It has a cellular or vesicular texture and a diagnostic mineral suite. The mineralogy consists of plagioclase, olivine (iddingsite), clinopyroxene, and magnetite. There are a few lath-shaped microlites of an unknown mineral in the black glassy matrix. The phenocrysts are commonly 2.0 mm in diameter or larger, but account for less than one percent of the rock. The black or banded pumice, or minerals derived from it, were recognized in 25 percent of the thin sections studied.

The banded pumice is composed of a mixture of the gray, brown, black, and white varieties. It is composed of nearly parallel bands of color that range in shades from black to white. The contacts between the bands are sharp; the band widths vary from less than 1/25 to 1/2 inch or more. The white bands seem to contain a mineral suite identical to that of the Rattlesnake ignimbrite. The black bands contain the same mineral suite as the black pumice clots.

This black and banded pumice was not observed on outcrop in the John Day Valley (Enlows, 1969, oral communication) but fragments and minerals from it were observed in thin section by the author. It was also observed in thin section from the upper ignimbrite in Devine Canyon. Beeson (1969) refers to an ash flow west of Diamond Valley (south of Burns in the Harney Basin) that contains white and black banded pumice. He reports that this unit might be the upper Danforth-Rattlesnake equivalent since the trace element contents are similar. An exposure of an ignimbrite along the south shore of Harney Lake also contains large pumice fragments of all three types.

Numerous black pumice clots were collected from an unusually thick nonwelded section in a quarry near Grindstone Creek. They were disaggregated and the phenocrysts were concentrated. It was subsequently learned that some of the phenocrysts are glomeroporphyritic (Figure 25) and are contained in a dense nonvesiculated red or black glass (90 percent black). A thin section of this material revealed that olivine and plagioclase occur in about equal amounts, augite is subordinate, and magnetite is only present in trace amounts.

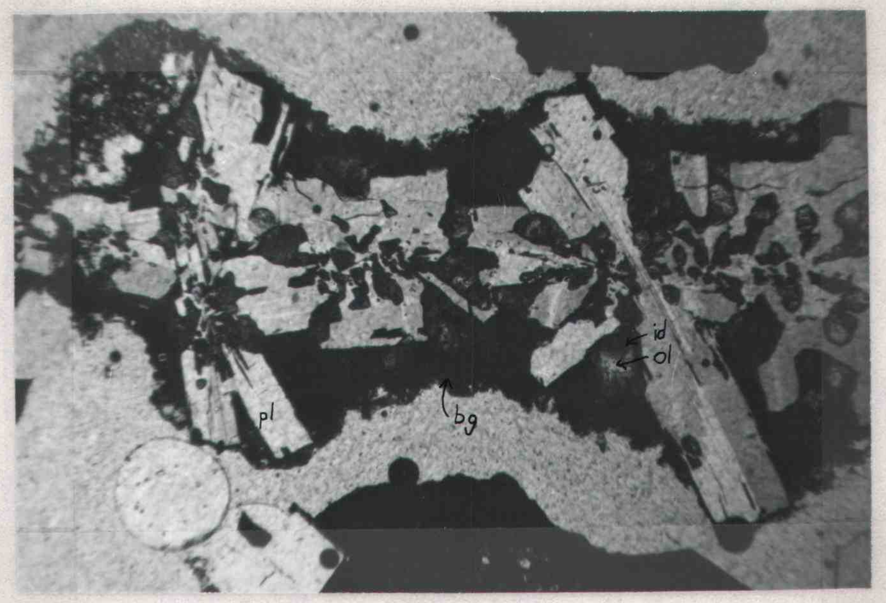


Figure 25. Photomicrograph of glomeroporphyritic phenocrysts of plagioclase (pl), olivine (ol), and iddingsite (id, alteration of olivine) contained in a dense black glass (bg). This fragment was derived from the black pumice (approximately 2.4 mm x 1.6 mm).

The plagioclase occurs in subhedral to euhedral lath-shaped crystals. Rinds of black glass cover the crystal surfaces, and there is little or no alteration. Optical studies using Michel-Levy's method (Kerr, 1959) give an An content of 68 percent. The optic sign is positive. The indices of refraction were determined for alpha (1.565) and gamma (1.573). These results plotted on Chayes' plagioclase diagram (Kerr, 1959) show an An content of 71 percent. Thus the feldspar is probably high labradorite to low bytownite.

The olivine crystals are altered either partly or more commonly, completely to iddingsite. Under the binocular microscope they are yellowish brown when altered, or amber with a resinous luster when fresh. Some are euhedral showing well-developed orthorhombic crystal forms.

Optical studies on three fresh olivines produced the following results:

alpha = 1.684	gamma = 1.726
alpha = 1.687	gamma = 1.727
alpha = 1.689	gamma = 1.730
optic angle: 80-90°	
optic sign: negative	

When indices of refraction are plotted on the atomic % Fe^{+2} diagram of Deer, Howie and Zussman (1962, vol. 1), the relative compositions of these olivines are 26, 31, and 32 percent fayalite respectively.

The clinopyroxene crystals are probably augite. In reflected light they are very dark green (almost black, except on the thin edges); in thin section the crystals are colorless. Some crystals exhibit well-developed monoclinic forms. The indices of refraction and other optical data determined on a few grains are given below. The optic and extinction angles were determined with the aid of the universal stage.

alpha = 1.694	gamma = 1.719
alpha = 1.697	gamma = 1.715
2V = 61°	
2V = 48 ?	
2V = 46 ?	
optic sign: positive	
extinction angle: 45°	

The pyroxenes are fresh and free of alteration.

A similar mineral suite has been described from several porphyritic silicic glasses by Carmichael (1960). These came from acid dikes, margins of acid lavas, and the chilled margins of acid intrusions on Iceland and the British island of Arran. All of the residual glasses are more silicic than the black pumice discussed above. Their phenocryst content described is generally less than 15 percent and the mineralogy of most consists chiefly of plagioclase, pyroxene, olivine, and iron ore.

The chemistry of the black pumice is presented in Table 21. It has a differentiation index of 69. The average quartz latite of Daly (1914, in: Thornton and Tuttle, 1960) has a differentiation index of 68. Using Rittmann's (1952) "Nomenclature of Volcanic Rocks" the subsequent calculations indicate the black pumice is a latite.

Table 21. Chemical and normative analyses.

Sample No.	1 18-D	2 395-3-B	3 395-3-W
	Chemical Analyses (weight %)		
SiO_2	64.9	76.32	77.26
TiO_2	1.1	0.16	0.14
Al_2O_3	13.9	13.01	12.69
FeO	6.6	0.61	0.29
Fe_2O_3	--	0.72	0.54
MnO	0.021*	0.05	0.03
MgO	1.8	0.02	0.03
CaO	3.2	0.27	0.26
Na_2O	3.5*	2.94	3.34
K_2O	3.8	5.87	5.41
H_2O	--	(3.05)	(3.04)
P_2O_5	0.58*	0.03	0.01
	99.40	100	100
	Normative Analyses		
quartz	17.24	35.53	36.05
orthoclase	22.45	34.69	31.97
albite	29.59	24.89	28.24
anorthite	10.85	1.30	1.23
corundum	1.81	1.39	0.08
wollastonite	--	--	--
enstatite	4.50	0.05	0.08
hypersthene	10.37	1.55	1.25
apatite	1.27	0.07	0.02
magnetite	--	--	--
ilmenite	2.07	0.30	0.26
	100.15	99.74	99.18
Differentiation Index	69	95	96

(1) Black pumice--analyses by E. M. Taylor and Monty Elliott, all Fe reported as FeO, water-free.
* Analyses by Rocky Mountain Geochemical Corporation.

(2) Black (brown) shards from Devine Canyon (data after Beeson, 1969).

(3) White shards from Devine Canyon (data after Beeson, 1969).

Chemistry

Most ash flows show little or no vertical or lateral variations in their chemical or mineralogical compositions (Lipman, Christiansen and O'Connor, 1966). In recent years there have been reports on a number of ash-flow sheets that show a more mafic top overlying a more silicic base, or successive flows that become more basic toward higher stratigraphic levels (Ratté and Steven, 1964; Smith and Bailey, 1966; Fisher, 1966; Lipman, Christiansen and O'Connor, 1966; Lipman, 1967). Cook (1968) reported an inverse of this, with a mafic crystal-rich zone on the bottom and silicic crystal-poor zone on top.

The Rattlesnake ignimbrite member is rhyolitic and does not seem to vary significantly in its chemical composition. This is true for the major oxides both vertically and laterally within the unit. Table 22 contains chemical analyses for the Rattlesnake ignimbrite from the Paulina Basin, John Day Valley, and Devine Canyon. The ignimbrite was examined for vertical variations in its chemical composition by analyzing a sample from the base and top of a thick section on Powell Creek near Rager Ranger Station. The results presented in Table 22 (numbers 2 and 3) show no significant change in the chemical composition from top to bottom. Chemical analyses of samples from Cottonwood Creek in the John Day Valley (Enlows, unpublished data) indicate that the minor variations that do occur are not

Table 22. Chemical and normative analyses of the Rattlesnake ignimbrite.

	1	2	3	4	5*	6
Sample No.	147**	1-B**	1-T**	Average	Average	0-19-2
			Chemical Analyses (weight %)			
SiO_2	73.5	75.8	75.8	75.0	75.3	75.85
TiO_2	0.34	0.18	0.13	0.22	0.22	0.22
Al_2O_3	13.5	13.4	13.2	13.4	12.2	12.59
FeO	2.8	1.5	1.82	2.04	--	1.48
Fe_2O_3	--	--	--	--	0.79	0.11
MnO	0.076*	0.011*	0.029*	0.039	0.041	0.04
MgO	0.9	0.4	0.4	0.6	0.58	0.04
CaO	1.1	0.46	0.28	0.61	0.30	0.29
Na_2O	2.9*	3.6*	4.0*	3.5	3.36	3.91
K_2O	5.1	4.80	4.33	4.7	3.74	4.18
H_2O	--	--	--	--	?	0.90
P_2O_5	0.06*	0.03*	0.03*	0.04	0.01	0.03
	100.27	100.18	100.01	100.15	96.54	99.64
			Normative Analyses			
quartz	31.47	33.93	33.46	33.36	39.55	34.64
orthoclase	30.14	28.36	25.59	27.77	22.10	25.30
albite	24.52	30.44	33.82	29.59	28.41	35.96
anorthite	5.12	2.11	1.22	2.80	1.43	1.27
corundum	1.29	1.40	1.44	1.02	2.06	1.32
wollastonite	--	--	--	--	--	--
enstatite	2.25	1.00	1.00	1.50	1.45	0.11
hypersthene	4.59	2.26	3.18	3.46	1.03	--
apatite	0.13	0.07	0.07	0.09	0.02	0.06
magnetite	--	--	--	--	--	--
ilmenite	0.64	0.34	0.24	0.41	0.41	0.25
apatite	0.13	0.07	0.07	0.09	0.02	0.06
hematite	--	--	--	--	--	1.06
	100.15	99.91	100.02	100	96.46	99.97
Differentiation Index	86	93	93	91	90	96

(1) Near Davin Spring.

(2) Basal sample in roadcut near Powell Creek.

(3) Upper sample in roadcut near Powell Creek.

(4) Average of 1, 2, and 3.

(5) Average of five samples from the John Day Valley region (Enlows' unpublished data).

(6) Top ash flow of Danforth Formation near Burns (data after Beeson, 1969).

* Analyses by Rocky Mountain Geochemical Corporation (Fe_2O_3 recalculated to FeO in norm).

** Analyses by E. M. Taylor and Monty Elliott, all Fe reported as FeO, water-free.

consistent.

Alteration of the glass, especially in the porous parts of the ash flow, by hydration, devitrification and leaching may alter significantly the silicon, aluminum and sodium values (Lipman, 1965). It has also been reported that deuteric alteration can produce vertical chemical variations by potassium-sodium exchanges and magnesium and iron redistributions (Scott, 1966). It seems possible that these factors could account for the small chemical variations that do occur. The unusually low sodium value for number 1 in Table 22 is an example.

The trace element abundances in the Rattlesnake from the John Day Valley and the Harney Basin were investigated by Beeson (1969). He found that trace element variations within the Rattlesnake ignimbrite member were minor compared with the differences between discrete ash flows. The poorly zoned ash flow in the John Day Valley showed little internal variation whereas the strongly zoned ash flow in the Harney Basin showed vertical variations in certain trace elements. It has been suggested by Beeson that the zoning was instrumental in redistributing the elements.

The chemical analyses of the Rattlesnake ignimbrite (Table 22) are very similar to the "average alkali rhyolite and rhyolite obsidian" of Nockolds (1954). The average differentiation index of the Rattlesnake ignimbrite member is approximately 92.

Differentiation Index Chart

	Number of Samples	D. I.
Daly's (1914; in: Thornton and Tuttle, 1960) averages:		
alkali rhyolite		91
rhyolite		88
Nockolds (1954) averages:		
alkali rhyolite and rhyolite obsidian	(21)	94
This report:		
Rattlesnake ignimbrite average	(8)	92
Crystal-poor ignimbrite average	(2)	95
Crystal-rich ignimbrite average	(2)	90
Mascall ignimbrite	(1)	89

Age Dating

Radiometric dating of the Rattlesnake ignimbrite member in the Paulina Basin area was conducted for the purpose of supporting the correlation with the ignimbrite member of the Rattlesnake Formation in the John Day Valley. Previous dating on samples from the John Day Valley yielded an average date of 6.05 million years (Table 23). This is exclusive of sample W-14 of Dalrymple et al. (1967) which is considered to be anomalous. Enlows (1969, oral communication) has two anomalous samples from Cottonwood Creek, one giving a very high date and the other a very low date. These are also not included in this average.

Two dates on the ignimbrites from the Paulina Basin area were

Table 23. Potassium-argon age dates and magnetic data on the Rattlesnake ignimbrite.

Sample Number	Location	Age Million Years	Polarity
	Paulina Basin		
KA 1-2	Powell Creek roadcut	6.5 (± 0.5)	reversed
KA 147	Davin Spring	5.8 (± 0.4)	-
	John Day Valley		
W-14*	Birch Creek (top)	6.69 (± 0.20)	reversed
W-15*	Birch Creek (base)	5.95 (± 0.18)	reversed
KA 1206**	10.6 miles east of Dayville	6.4	-
E-71-67***	Prairie City	5.8 (± 0.5)	

* Dalrymple et al., 1967

** Evernden and James, 1964

*** Enlows, unpublished date

made. One sample was collected from the lower nonwelded zone in a roadcut near Powell Creek about one mile west of Rager Ranger Station. This sample contains colorless shards, a few crystals, and xenoliths. It yielded a date of 6.5 (± 0.5) million years on 12.582 grams of fresh alkali feldspar (41.5 % Or). These were hand picked from the glassy matrix, carefully excluding all suspected xenocrysts.

The other sample was selected from an exposure one-fourth mile west-southwest of Davin Spring, immediately north of the Paulina-Suplee road. The matrix consists of 75 percent brown shards and 25 percent colorless shards. The surfaces of the anorthoclase crystals have a thin rind of bubbly brown glass. An age date of 5.8 (± 0.4) million years was obtained on 12.443 grams of the feldspar (29% Or).

The above dates are compatible with those already given for the Rattlesnake ignimbrite. Thus, an average date on this unit is 6.1 million years utilizing all dates except those suspected to be anomalous.

It has been reported by Evernden and James (1964) that alkali feldspars in the intermediate potassium range are not retentive of their argon in older rocks, and in some instances in Tertiary rocks. The Rattlesnake feldspars are within the range of poor retentivity. However, the reliability of most of the Rattlesnake dates is supported by the relatively young age and the near coincidence of the dates.

Geomagnetic Polarity

Paleomagnetism studies were conducted in the laboratory on oriented samples of the Rattlesnake ignimbrite member. These were collected from several widely separated localities in the Paulina Basin as well as from different positions in the vertical section. The results of approximately 50 percent of the samples were "reverse" polarity. The polarities of the other samples were too weak and thus did not produce significant readings.

The results are in accord with measurements conducted on the ignimbrite member of the Rattlesnake Formation from the John Day Valley (Dalrymple et al., 1967; Enlows, 1969, oral communication). The upper ignimbrite member of the Danforth Formation in Devine Canyon also gave a "reversed" polarity reading.

Origin of the Hybrid Shards and the Black and Banded Pumice

Glass of two colors is restricted to the Rattlesnake ignimbrite and is not present in the other ash flows in this area. The origin of the hybrid glass is a perplexing problem. It is common for tuffs to have colorless, or brown, or salmon, or tan shards (Carozzi, 1960), but the presence of two types in the same unit is considered rare. Previous reference to varicolored glass either in the matrix or in banded pumice was reported at Lassen Peak (MacDonald and Katsura, 1965), Mount Katmai and Novarupta (Williams, Curtis and Juhle, 1956; Curtis, 1958), Breiddalur central volcano in Iceland (Walker, 1963), Meseta Central Occidental in Costa Rica (Williams, 1952), Taupo area in New Zealand (Ewart, 1963), and the Rattlesnake ignimbrite (Beeson, 1969). The two phases do not seem to be as intimately mixed in the above as they are in the Rattlesnake with the exception of the following:

Williams (1952, p. 176)

> ...most of the welded tuffs show an intimate mixture of varicolored glass fragments, the refractive indices of which suggest a range in silica content from about 58 to 68 percent.

Walker (1963, p. 47)

> The bed is more likely to be a lava than a welded tuff. Microscopically the rock is seen to be an intimate mixture of colorless acid glass, and a fine-grained near glassy black basalt. The rock is interpreted as an emulsion of acid and basic magmas . . . .

Beeson (1969) infers that the black pumice and the "black" shards are equivalent but this is inaccurate (the black shards are actually brown in thin section). The chemical composition of the brown shards and the black pumice are quite different (Table 21). The two types of glass shards, brown and colorless (or white), are rhyolitic in composition. In contrast the black pumice is latitic. It has a differentiation index of 69 compared to 95 and 96 for the brown and colorless shards.

The origin of banded pumice, or its mafic phase, has been suggested in the following ways:

(1) Incomplete mixing of two distinct magmas was suggested by Curtis (1968), and MacDonald and Katsura (1965);

(2) The partial melting of country rock around the edge of the magma chamber producing a more basic phase was suggested by Ewart (1963);

(3) Tuttle and Bowen (1958) discuss the occurrence of a basic zone about the edge of the magma chamber produced by silica and feldspar removal from the melt by vapor transport, thus concentrating the more mafic components.

The first hypothesis seems to be the most likely for the black and banded pumice in view of the mineralogy, chemistry, and the lack of partially melted xenoliths from the country rock.

The colorless and brown shards are nearly similar in amounts of the major oxides. Beeson (1969) reported the brown shards are higher in total Fe and K_2O, and lower in Na_2O. He also reported a distinct difference in the trace element abundances. After a discussion on the possible mechanisms for producing hybrid glass, Beeson (1969) concludes with the following:

> . . . no statement may be made as to what process produced this two-glass ash-flow tuff, but the evidence points to simultaneous eruption of two liquids from the same vent.

> Whether the glasses are the results of unmixing of a once-homogeneous melt or the mixing of two-melts of separate origin cannot be determined with the present evidence.

The author cannot add much to the comprehensive discussion by Beeson except to say that in view of a probable separate source for the black pumice, it would seem unwise to suggest three liquids of separate origin mixing during a simultaneous eruption from the same vent. The X-ray diffraction studies on the alkali feldspars indicate they are all approximately the same composition from any one sample. This suggests they probably were formed under nearly the same conditions, thus precluding separate magma chambers for the brown and colorless shards.

Summary of a Regional Rattlesnake Ignimbrite Correlation

The basis for concluding that the Rattlesnake ignimbrite member in the Paulina Basin is equivalent to the ignimbrite member of the Rattlesnake Formation in the John Day Valley has been presented in the preceding pages. The following is a summary of the facts that support this conclusion:

(1) The ignimbrite overlies Mascall sediments of Barstovian age in both areas;

(2) The mammalian fauna collected from below and above the ignimbrite in the Paulina Basin was identified as a

Rattlesnake assemblage of Hemphillian age;

(3) The lithology is always a pumiceous, crystal-poor vitric tuff and has similar modal analyses throughout;

(4) The mineralogy consists of alkali feldspar, quartz, magnetite, green iron-rich augite (?), and zircon;

(5) Hybrid glass (brown and colorless) is characteristic of all exposures except those near Prairie City;

(6) There is only a three percent difference in the average feldspar composition between the John Day Valley region and the Paulina Basin. Moreover, there is a sequential increase in the orthoclase content of the feldspars from the John Day Valley region to Devine Canyon;

(7) The black pumice or the cognate minerals derived from it occur in the ignimbrite in both areas;

(8) The potassium-argon dates on two Paulina Basin samples are in agreement with published and unpublished dates for the Rattlesnake ignimbrite in the John Day Valley;

(9) The chemical analyses are very similar and a rhyolitic composition is indicated;

(10) The magnetic polarity of the ignimbrite is weakly "reversed" for all samples checked.

Those preceding factors numbered (3), (4), (5), (6), (7), (9), and (10) are applicable also for extending the ignimbrite correlation south to include the upper ignimbrite of the Danforth Formation in the Harney Basin. In addition, the following also support an equivalent relationship:

(1) On the basis of trace element abundances, expecially selenium, thorium, hafnium, cesium, tantalum, and REE, it has been suggested by Beeson (1969) that the ignimbrite member of the Rattlesnake Formation and upper ignimbrite member of the Danforth Formation are equivalent;

(2) There is a continuity of ignimbrite outcrops from Murderers Creek to the Harney Basin;

(3) The age of the Danforth Formation was tentatively placed in the Pliocene on the basis of five species of fresh water shells: Pisidium sp., Pompholix ? sp., Fossaria ? sp., Fluminicola fusca Haldeman, Gyraulus parvus Say (Piper, Robinson and Park, 1939).

STRATIGRAPHY OF THE PLIOCENE SEDIMENTARY ROCKS

The occurrence of Pliocene sedimentary rocks in the thesis area was reported by Forth (1965) for a sequence of poorly indurated silts, sands, and gravels resting on the Rattlesnake ignimbrite member and lying beneath the Ochoco Basalt. These were included in the Rattlesnake Formation at that time. The sedimentary sequence below the Rattlesnake ignimbrite member and above the crystal-rich ignimbrite member was previously assigned to the Mascall Formation (Forth, 1965). Radiometric age dating of the crystal-rich member and fossils collected from the sedimentary rocks below and above the Rattlesnake ash flow indicate that these rocks are middle Pliocene in age.

Lower Sedimentary Sequence

The strata lying between the crystal-rich and the Rattlesnake ignimbrite members are confined to the syncline between Beaver and Grindstone Creeks (Figure 26).

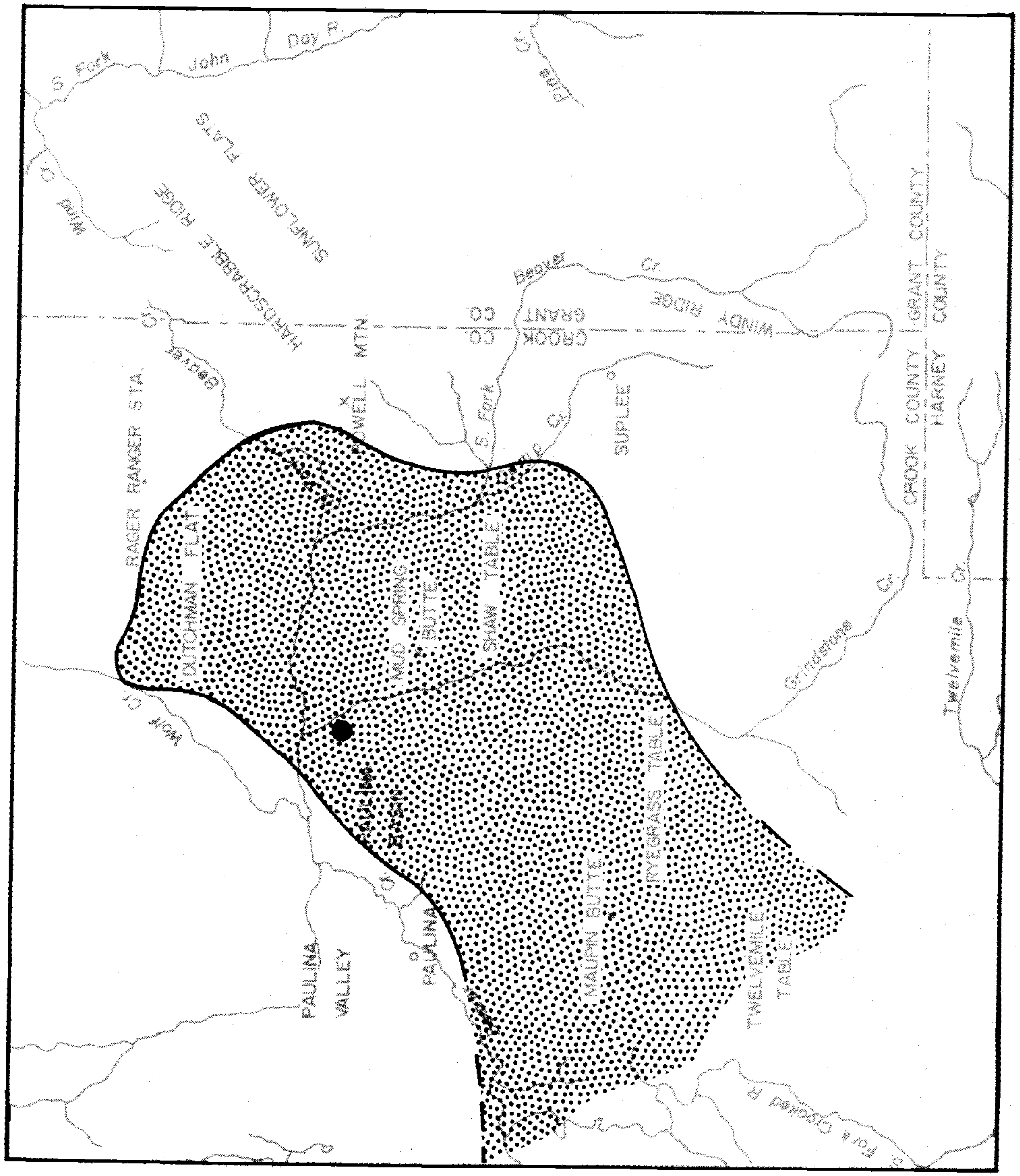
The sedimentary sequence forms covered slopes between the two ignimbrites, the surface of the slope commonly exhibiting an array of varicolored chert pebbles. The maximum thickness is unknown but probably it does not exceed 100 feet. Two good exposures near the edge of the outcrop area were measured. One is 8 feet thick in a

Figure 26. Distribution map of Pliocene sedimentary rocks that occur between the crystal-rich and Rattlesnake ignimbrite units.

Scale: 1/4 inch = 1 mile

Sediments

Fossil locality


S. Fork John Day R.
Pine Cr.
SUNFLOWER FLATS
HARDSCRABBLE RIDGE
Wind Cr.
Beaver Cr.
GRANT CO.
CROOK CO.
WINDY RIDGE
POWELL MTN.
RAGER RANGER STA.
SUPLEE
S. Fork
GRANT COUNTY
CROOK COUNTY
HARNEY COUNTY
DUTCHMAN FLAT
MUD SPRING
BUTTE
SHAW TABLE
Grindstone Cr.
Twelvemile Cr.
Wolf Cr.
RYEGRASS TABLE
MAUPIN BUTTE
TWELVEMILE
TABLE
PAULINA
VALLEY
PAULINA
Fork Crooked R.

road cut near Powell Creek, the other is 20 feet thick in the South Fork of the Crooked River Canyon.

The lithology consists predominantly of tuffaceous volcanic sandstones that have considerable silt, clay and intermixed gravels. The pebble-size gravels are lens-shaped bodies composed of vari-colored cherts, basalts, and metasediments (?). The origin is fluviatile.

Upper Sedimentary Sequence

The upper sedimentary sequence has about the same area of distribution as the lower (Figure 27). This unit rests on the Rattle-snake ignimbrite member and is overlain by the Ochoco Basalt at Dutchman Flat and Ryegrass Table.

Fair exposures occur on a small hill three-quarters of a mile northwest of Davin Spring (NW1/4 SE1/4 sec. 4, T. 7 S., R. 24 E.). This section is 184 (+) feet thick and consists of coarse- to fine-grained tuffaceous volcanic sandstones and pumiceous volcanic granule-conglomerates capped by gravel (Table 24). The thickness decreases to 125 feet at the mouth of Sugar Creek Canyon and to 75 feet at Alkali Creek Canyon (Forth, 1965) on the north edge of Rye-grass Table.

Figure 27. Distribution map of the Pliocene sedimentary rocks that occur between the Rattlesnake ignimbrite and the Ochoco Basalt.

Scale: 1/4 inch = 1 mile

Sediments

Fossil localities

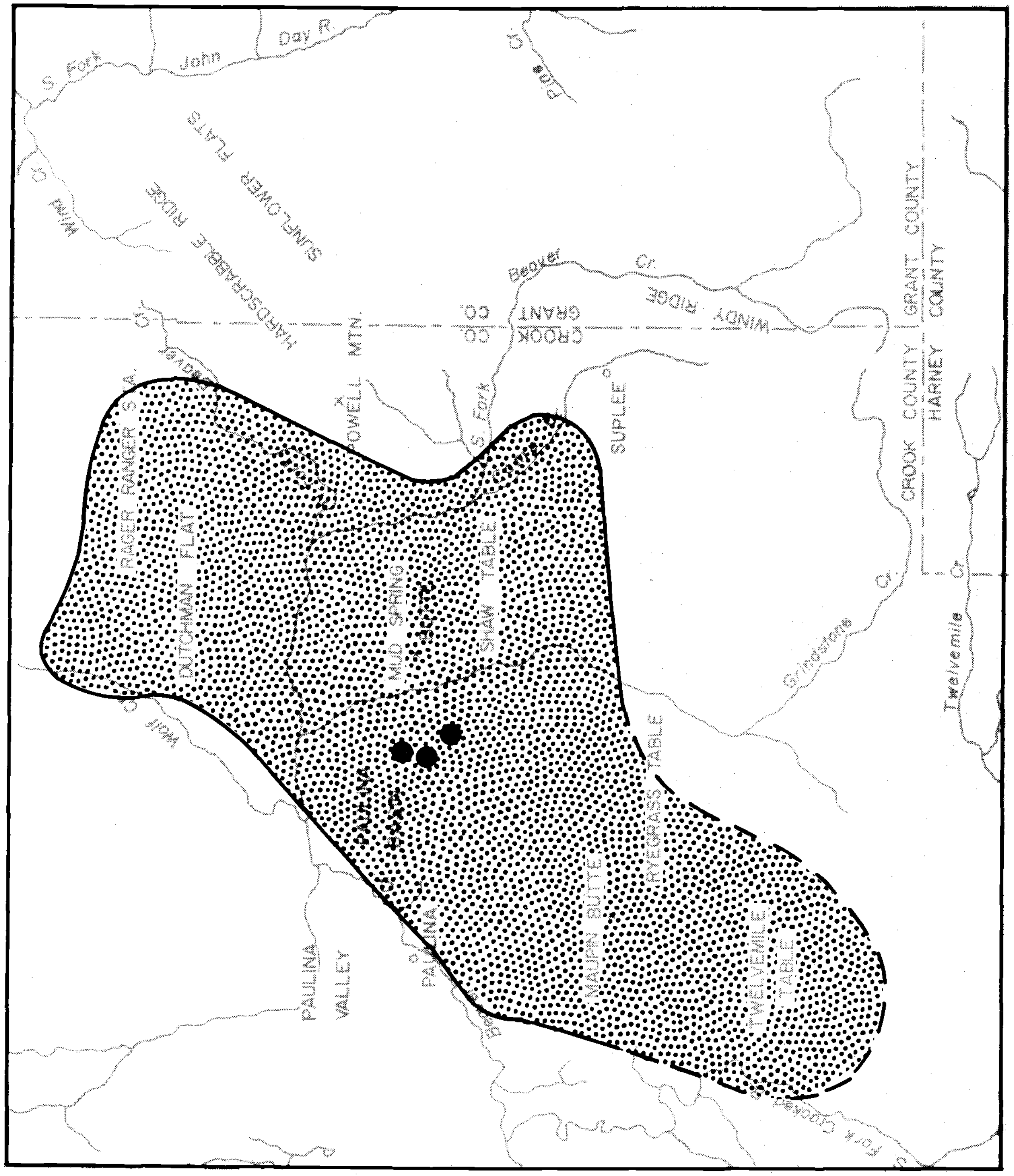

S. Fork
John
Day R.
Pine Cr.
Wind Cr.
SUNFLOWER FLATS
HARDSCRABBLE RIDGE
Beaver
Cr.
WINDY RIDGE
GRANT CO.
CROOK CO.
GRANT COUNTY
CROOK COUNTY
HARNEY COUNTY
POWELL MTN.
S. Fork
SUPLEE
RAGER RANGER S.A.
DUTCHMAN FLAT
MUD SPRING
SHAW TABLE
Grindstone Cr.
Twelvemile Cr.
Wolf Cr.
RYEGRASS TABLE
PAULINA
MAUPIN BUTTE
TWELVEMILE TABLE
PAULINA VALLEY
Fork Crooked

Table 24. Grindstone Creek stratigraphic section, upper sedimentary rocks of Pliocene age (NW1/4 SE1/4 sec. 4, T. 17 S., R. 24 E.).

Thickness (in feet)	Lithology
7	Gravel: pebbles to cobbles, subangular to well rounded; welded tuff, chert, metasediments (?), pebble conglomerate, quartzite, basalt, and dacite
10	Pumiceous Volcanic Sandstone and Conglomerate: yellow brown (10YR5/4); moderately consolidated; 50 percent white pumice (1/4 inch max.) Volcanic Siltstone: orange brown (10YR6/4); weakly consolidated
5	Volcanic Sandstone: light olive gray (5Y5/2); coarse grained, massive; moderately consolidated
16	Pumiceous Volcanic Sandstone: very pale orange (10YR8/2); 10 percent white pumice (1/4 inch max.); moderately consolidated
10	Covered Slope
16	Tuffaceous Volcanic Sandstone: orange brown (10YR7/3); medium grained; non-bedded
22	Tuffaceous Volcanic Sandstone: orange brown (10YR6/4); very fine grained, (partially covered slope)
30	Covered Slope
10	Tuffaceous Volcanic Sandstone: grayish orange (10YR7/4); medium grained; moderately indurated
60	Covered Slope (base of section not exposed)
186	

Fossils

A number of mammalian fossils were found in the Paulina area. *Teleoceras* sp. and a small camel of Pliocene age (Shotwell, 1969, oral communication) were found in the lower sediments on the top of a small knoll south of the Lister Ranch along Beaver Creek (Figure 26). The bone fragments were not found in place but were float material presumably weathered from the immediate vicinity.

A considerable number of mammalian fossils were collected from the upper sediments in the vicinity of the measured section (Figure 27). These also were float material. Dr. J. A. Shotwell (1969, oral communication) identified them as a Rattlesnake assemblage of Pliocene age.

Pliohippus ?
Teleoceras sp.
Megatylopus sp.
large camel
small camel

Pliohippus ? and *Teleoceras* sp. were previously reported by Mote (1939) from the "Harney Formation" (Rattlesnake; presumably along the Crooked River, but the exact locality is unknown).

DISTRIBUTION AND PROBABLE SOURCE OF THE RATTLESNAKE IGNIMBRITE

The Rattlesnake ignimbrite covered approximately 600 square miles in the area of this investigation. The average thickness is 30 feet and the calculated volume is 4 cubic miles.

Thayer (1952) postulated that the Rattlesnake ignimbrite covered approximately 2500 square miles in the John Day Valley, Murderers Creek, Bear Valley, and Paulina areas and that the ignimbrite extended an unknown distance to the south. Walker (1969) suggested that the upper ash flow of the Danforth Formation covered 3000 square miles in the Harney Basin. He reported an average thickness of 60 feet for the ignimbrite and a volume of 45 cubic miles (Walker, 1970). Campbell _et al_. (1958) postulated a total volume for the ash flow of 20 cubic miles.

The author estimates that the Rattlesnake ash-flow sheet extended over 6500 square miles in the valleys of the John Day River, North and South Forks of the John Day River, Mountain Creek, Murderers Creek, the Paulina area, Bear Valley, and the Harney Basin. The original volume would have approximated 55 cubic miles using an average thickness of 45 feet.

Little is known of the type of eruption that produced the Rattlesnake ignimbrite. Hausen (1954) suggests that the Pliocene and

Miocene silicic extrusives that cover many thousands of square miles in Idaho and Oregon erupted from craters and fissures. The possibility of a crater eruption is not likely considering the volume of material extruded. Smith (1960b) indicates that the maximum volume for a known crater eruption is about 15 cubic kilometers. It is more likely therefore, that the Rattlesnake eruption was from fissures, multiple vents or a subsidence structure such as a caldera.

Walker (1969) suggests a possible source vent in the Buzzard Creek area. This vent is in a graben probably related to the Brothers fault zone and is situated a few miles west-southwest of Harney Lake. Walker (1970) later proposed that the major source for the ash-flow sheet was located in the area between Burns, Harney Lake and Malheur Lake. Walker (1969) indicated that faulting and basin collapse were contemporaneous with the eruption of the ash flows.

The factors that indicate a source for the ash flow in the Harney Basin are:

(1) The average thickness of the ash-flow sheet decreases from the Harney Basin to the northwest;

(2) "A source in the area south of the Ochoco Mountains is suggested by progressive increase in size and abundance of pumice fragments and increase in degree of vitreousness and devitrification toward the southwest" (Thayer, 1952);

(3) There is a substantial increase in the zonation of the

ash-flow sheet toward the Harney Basin. This is denoted by an increase in the amount of devitrification, welding, gas cavities, and the occurrence of lithophysae and spherulite zones in Devine Canyon;

(4) X-ray perthites found only in the Devine Canyon feldspars indicate a slower cooling rate for the ash flow;

(5) There is a systematic increase in the weight percent of orthoclase in the alkali feldspars toward the Harney Basin (Figure 28).

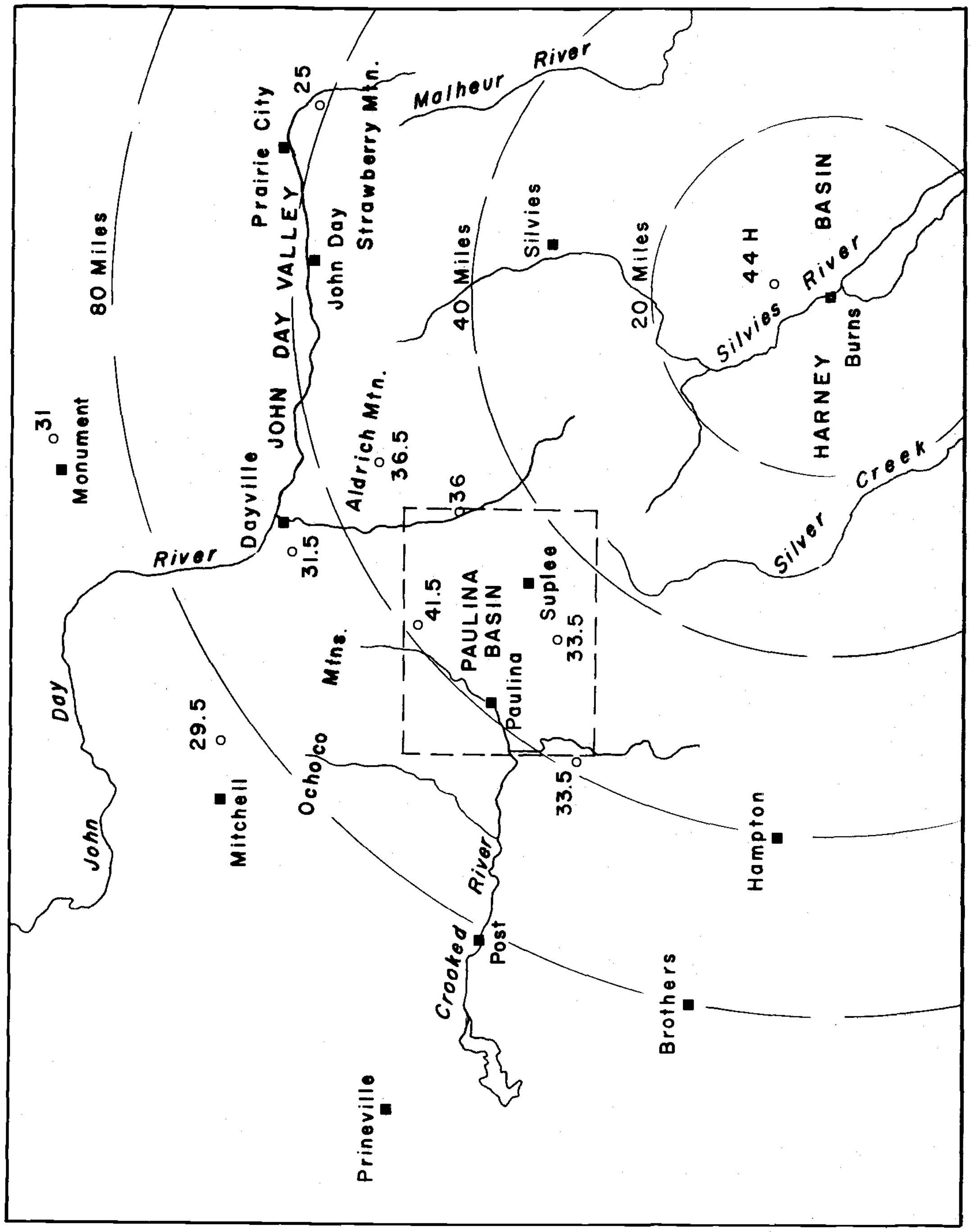
The chemistry of the major oxides in the ash flow seems to be uniform. Therefore, the changing feldspar composition can probably be attributed to the physical conditions in the magma chamber. Ewart (1965) proposed that the vapor pressure decreased with depth in the magma chamber. He also suggests a drop in the vapor pressure produced an outer sodic zone on sanidine phenocrysts from the Whakamaru ignimbrite in New Zealand. This could account for a decrease in the orthoclase content of the Rattlesnake feldspars with increasing depth in the magma chamber. Thus, eruption of the magma chamber might produce a zoned ash-flow sheet with respect to feldspar composition. The first material erupted would be deposited near the vent and would consequently be more potassic. The remainder would be deposited farther and farther outward, gradually becoming more sodic. The vertical sequence would then be more sodic at the top

Figure 28. Map of central Oregon depicting Burns as the probable focus for the Rattlesnake ash flow. The weight percent orthoclase of the alkali feldspars is plotted at the sample locations.

o Samples from base of ash flow

H Homogenized feldspars

— — — Outline of thesis area


80 Miles
40 Miles
20 Miles
JOHN DAY VALLEY
Prairie City
25
John Day
Strawberry Mtn.
Malheur River
Silvies
HARNEY BASIN
44 H
Silvies River
Burns
Silver Creek
Aldrich Mtn.
36.5
36
31
Monument
Dayville
John Day River
31.5
PAULINA BASIN
41.5
Suplee
33.5
Paulina
Ochoco Mtns.
29.5
Mitchell
33.5
Hampton
Crooked River
Post
Brothers
Prineville

because of inversion of the material from the magma chamber. The feldspars from Powell Creek and Cottonwood Creek show a decrease in the orthoclase content from the bottom to the top of the ignimbrite section (Table 2). Smith and Bailey (1966) described a situation in which the sodic content of the feldspars increases from bottom to top in the Bandelier Tuff.

The theoretical maximum travel distance for an ash flow was previously thought to be 100 miles (Smith, 1960b). If the Rattlesnake ash flow traveled to the John Day Valley by way of the South Fork, then east beyond Prairie City (Thayer, 1952), the total travel distance from Burns, Oregon would be approximately 120 miles. This would make the rocks east of Prairie City the farthest removed from the source; likewise, they have the lowest weight percent orthoclase in the feldspars. The Rattlesnake ignimbrite outcrop on Deer Creek, near Monument, Oregon is the farthest direct distance from Burns--about 90 miles.

CONCLUSIONS

The principal conclusions drawn from this study are:

(1) Four Tertiary ignimbrites occur in the Paulina area and they range in age from 16 to 6 million years;

(2) The oldest ash flow is Miocene in age and belongs to the Mascall Formation; the remaining three are Pliocene in age and have been assigned to the Danforth Formation. They are from bottom to top: the crystal-rich ignimbrite member, the crystal-poor ignimbrite member, and the Rattlesnake ignimbrite member. They are equivalent to the three Danforth ignimbrites that are exposed in Devine Canyon;

(3) The youngest ignimbrite, previously referred to as Rattlesnake (and Harney), is equivalent to the ignimbrite member of the Rattlesnake Formation in the John Day Valley;

(4) The author suggests that the Mio-Pliocene boundary in the Paulina Basin be placed at the base of the crystal-rich ignimbrite;

(5) All four ignimbrites appear to be single ash-flow units deposited by a nuée ardente-type volcanic eruption;

(6) The Rattlesnake and the Mascall ignimbrite members are in some respects similar, making field identification difficult;

(7) All of the ash flows are rhyolitic. However, each ignimbrite has distinctive lithologic and petrographic characteristics that facilitate identification;

(8) All four of the units are vitric tuffs; however, the crystal-rich ignimbrite is also a crystal-vitric tuff.

(9) The Rattlesnake ignimbrite is not chemically zoned with respect to the major oxides;

(10) The source for the Rattlesnake ignimbrite is probably in the Harney Basin;

(11) There does not seem to be a source for the ignimbrites within the area of this investigation;

(12) The Rattlesnake ash flow is believed to have traveled at least 90 miles and possibly 120 miles from its probable source.

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APPENDIX

APPENDIX

Sample Locations and Descriptions

Ignimbrite Member of the Mascall Formation

68- Confluence of Deer Creek and the South Fork of the John Day River; SW1/4 NW1/4 sec. 17, T. 16 S., R. 27 E.; bench former, lower ignimbrite of two, covered slope with occasional blocky outcrops; approximately 45 feet thick, base not exposed

68-1 -------------------------------------- 7 feet from bottom
Light olive gray (5Y6/1); porous; partially welded tuff; 10-15 percent white pumice; dark gray obsidian chunks (1/2 inch max.); basalt fragments (1/2 inch max.); 3 percent colorless phenocrysts (1/16 inch max.)

68-2 ------------------------------------- 37 feet from bottom
Light olive gray (5Y6/1); porous; partially welded tuff; 7 percent small white pumice fragments; black obsidian chunks (1/4 inch max.); xenoliths (1/4 inch max.); slight eutaxitic texture; 2-3 percent phenocrysts (1/16 inch max.)

110- Near Trout Creek; NE1/4 SW1/4 sec. 25, T. 17 S., R. 24 E.; rim former; 40 feet thick

110-1 -- near base
Light gray (N7); poorly welded tuff; very porous; 5 percent white pumice (1/2 inch avg.); 1 percent xenoliths (1 inch max.); 1-2 percent colorless phenocrysts (1/16 inch max.)

111- North of Trout Creek and the Paulina-Suplee road; SE1/4 NE1/4 sec. 25, T. 17 S., R. 24 E.; rim former; nonwelded base to partially welded top; about 15 feet thick

111-1 -- near base
Light olive gray (5Y6/1); very porous; weakly welded, friable tuff; 1 percent obsidian chunks (1/4 inch max.); small white pumice; minor lithic fragments (1/2 inch max.)

114- North of Trout Creek and the Paulina-Suplee road; SE1/4 NE1/4 sec. 25, T. 17 S., R. 24 E.; rim former, nonwelded base to a partially welded top

114-1 -- near top
Light olive gray (5Y6/1); partially welded tuff; porous; 1 percent white pumice (1/2 inch max.); a few small xenoliths; slight eutaxitic texture

Crystal-Rich Ignimbrite Member of the Danforth Formation

1- Roadcut near Powell Creek 1 mile west of Rager Ranger Station; NW1/4 sec. 31, T. 15 S., R. 25 E.; lower ignimbrite of two

1-1 Medium gray (N7); porous; partially welded tuff; 5 percent very pale orange (10YR8/2) pumice fragments (1/4 inch max.); 1 percent small colorless phenocrysts

8- Quarry 1 mile east of Sartain Ranch; NE1/4 SE1/4 sec. 17, T. 16 S., R. 24 E.

Pale red (10R6/2) overlying yellowish olive gray (5Y6/2) with a sharp contact, partially welded tuff, 5 percent colorless phenocrysts (1/8 inch max.)

101- South of Beaver Creek and Paulina; SW1/4 sec. 3, T. 17 S., R. 23 E.; forms edge of lower bench; base not exposed

Yellowish gray (5Y7/2); porous; nonwelded to partially welded tuff; 1 percent colorless phenocrysts (1/16 inch max.); 2-3 percent xenoliths of sediments (limonite spots to 1/4 inch) and a few basalt fragments

149- Half a mile southeast of Pendleton Spring; SE1/4 SW1/4 sec. 8, T. 19 S., R. 27 E.; covered slope

149-1 -- float
Greenish gray (5GY6/1), strongly welded tuff, slightly eutaxitic, 20 percent colorless phenocrysts (1/8 inch max.); a few lithic fragments (1/4 inch max.); minor collapsed pumice

180- West side of U. S. Highway 395 north of Burns, Ore.; NW1/4 sec. 33, T. 21 S., R. 31 E.; irregular blocky slope, lower welded tuff; 128 feet thick

180-2 -------------------------------------- 110 feet above base
Pinkish gray (5YR8/1); partially welded tuff; 10 percent colorless phenocrysts (1/8 inch max.); 1 percent pumice

183- East side of U. S. Highway 395 north of Burns, Ore.; NE1/4 NW1/4 sec. 9, T. 22 S., R. 31 E.

183-1 ----------------------------- 2-5 feet above road surface
Nonwelded crystal-rich tuff; light colored; 25 percent colorless phenocryst (3/16 inch max.)

Crystal-Poor Ignimbrite Member of the Danforth Formation

150- Half a mile southeast of Pendleton Spring; SE1/4 SW1/4 sec. 8, T. 19 S., R. 27 E., covered slope

150-1 -- float
Light gray (N7); strongly welded tuff; devitrified; occasional lenticular gas cavity (1/4 inch max), lined with dark brown iron oxide stain

181- West side of U. S. Highway 395 north of Burns, Ore.; NW1/4 sec. 33, T. 33 S., R. 31 E.; rim former, 35 feet thick; gas cavity zone from 3 to 35 feet from base

181-1 -- 2 feet above base
Grayish orange pink (5YR7/2); devitrified, strongly welded tuff, a few collapsed pumice fragments (1/2 inch max.); eutaxitic texture; dendrites

Rattlesnake Ignimbrite Member of the Danforth Formation

1- Roadcut near Powell Creek 1 mile west of Rager Ranger Station; NW1/4 sec. 31, T. 15 S., R. 25 E.; rim former, upper ignimbrite of two; 75 (+) feet thick

1-2 ---------------------------------------1-6 feet above base
Nonwelded tuff; colorless shards, 5 percent white pumice (2-1/2 inch max.); less than 1 percent colorless phenocrysts (1/16 inch max.); basalt xenoliths (10 inches max.)

1-3 --------------------------------------- 7 feet above base
Light olive gray (5YR6/1); partially welded tuff; low porosity; eutaxitic texture

1-4 --------------------------------------- 17 feet above base
Olive gray (5Y5/1); dense; strongly welded tuff, glassy luster; 1 percent phenocrysts

1-5 --------------------------------------- 30 feet above base
Light olive gray (5Y6/1); dense; strongly welded tuff; eutaxitic texture; devitrified; collapsed pumice fragments

1-6 --------------------------------------- 57 feet above base
Grayish orange pink to pale red (10R7/2); dense; strongly welded tuff; devitrified; eutaxitic texture; oxidized

1-7 ---top
Grayish orange pink (10R7/2); porous; partially welded tuff; dark brown collapsed pumice; eutaxitic texture

18- Quarry three-fourths mile west of Grindstone Creek; SW1/4 NE1/4 sec. 33, T. 16 S., R. 24 E.; base not exposed; nonwelded tuff; brown and colorless shards; black, white, brown, gray, and banded pumice fragments (15 inches max.)

18-L White pumice

18-D Black pumice

26- One mile east of Dry Paulina Creek; NE1/4 NW1/4 sec. 1, T. 16 S., R. 23 E.; rim former, 34 feet thick

26-1 ---------------------------------------1 foot above base
Poorly welded tuff; light colored shards; porous; friable; 3 percent white pumice fragments (3-1/2 inches max.); basalt lithics (1/2 inch max.)

26-2 -------------------------------------- 10 feet above base
Light gray (N7); partially welded tuff; porous; slight eutaxitic texture; collapsed white pumice (1 inch max.); basalt lithics (1/2 inch max.)

26-3 ---------------------------------11 feet above base (float)
Pinkish gray (5YR8/1); dense; strongly welded tuff; devitrified; low porosity; 3 percent collapsed pumice (2 inch max.); eutaxitic texture

26-4 ---------------------------------------19 feet above base
Grayish pink (5R8/2); dense; strongly welded tuff; devitrified; low porosity; 3 percent collapsed pumice (1 inch max.); eutaxitic texture

26-5 ---------------------------------------28 feet above base
Grayish pink (5R8/2); partially welded tuff; very low porosity

26-6 ---------------------------------------32 feet above base
Very light gray (N8); partially welded tuff; porous; 1 percent lithics (1/4 inch max.); white to gray collapsed pumice fragment (1 inch max.)

63- One-fourth mile north of Pine Creek; N1/2 NW1/4 sec. 24, T. 17 S., R. 26 E.; rim former; base not exposed; 21 (+) feet thick

63-1 -- (float)
Medium gray (N5); partially welded tuff; porous; 5 percent collapsed black, white and banded pumice (2-1/2 inch max.); 1 percent lithics (1/2 inch max.); slight eutaxitic texture

63-2 --- base of cliff
Medium gray (N5); dense, strongly welded tuff; glassy luster; 1 percent lithics (1 inch max.); collapsed pumice with black glassy luster (2 inches max.); colorless phenocrysts (1 inch max.); eutaxitic texture

63-3 --1 foot above base
Light brownish gray (5YR6/1); dense; strongly welded tuff; devitrified; a few small gas cavities; 1 percent collapsed pumice with black color (2-1/2 inch max.); eutaxitic texture

63-4 --10 feet above base
Pinkish brown gray (5YR7/1); dense; strongly welded tuff; devitrified; 5 percent brown collapsed pumice fragments (1 inch max.); 1 percent lithics (2-1/2 inch max.); eutaxitic texture

63-5 --16 feet above base
Grayish orange pink (5YR7/2); strongly welded tuff; devitrified; 1 percent collapsed brown pumice (1 inch max.); eutaxitic texture

68- Confluence of Deer Creek of the John Day River; SW1/4 NW1/4 sec. 17, R. 16 S., R. 27 E.; covered slope; base not exposed; 70 (+) feet thick

68-4 ---(float)
Light olive gray (5Y6/1); partially welded tuff, porous, 7 percent white, gray, and black collapsed pumice fragments (1-1/2 inches max.); a few lithics (1/4 inch max.); eutaxitic texture

68-5 ---(float)
Light olive gray (5Y6/1), porous, partially welded tuff; 3 percent white, gray, and banded pumice (1-1/2 inches max.); limonitic lithics (1/2 inch max.); eutaxitic texture

68-6 -- top of unit
Medium gray (N6); dense; strongly welded tuff; glassy luster; nondistinct collapsed pumice; eutaxitic texture

121- East side of Grindstone Creek Canyon; NW1/4 SW1/4 sec. 15, T. 18 S., R. 24 E.; rim former; 58 feet thick

121-1 ------------------------------------ 1-4 feet above base
Nonwelded basal tuff; colorless shards; 5 percent white pumice (4 inches max.); 1 percent basalt and chert lithics (2-1/2 inch max.)

121-2 --10 feet above base
Light gray (N7); partially welded tuff; porous; 1 percent partly collapsed white and black pumice

121-3 --16 feet above base
Olive gray (5Y5/1); dense, strongly welded tuff; glassy luster; 1 percent collapsed black pumice (2-1/2 inch max.)

121-4 --24 feet above base
Light brownish gray (5YR6/1); dense; strongly welded tuff; devitrified; 1 percent collapsed pumice; 1 percent colorless phenocrysts (1/16 inch max.)

121-5 --52 feet above base
Pinkish brown gray (5YR7/1); dense; strongly welded tuff; devitrified; 3 percent collapsed brown pumice (2 inches max.); abundant very small iron oxidized spots; 1 percent colorless phenocrysts (1/16 inch max.)

146- South Fork of the Crooked River Canyon; NW1/4 SE1/4 sec. 34, T. 18 S., R. 22 E.; rim former; 110 feet thick

146-1 --4 feet above base
Light gray; poorly welded tuff; friable; colorless and brown shards; 10 percent white to gray pumice (14 inches max.); 1 percent basalt and mudstone lithics (6 inches max.)

146-2 --16 feet above base
Light yellowish olive (5Y7/1); poorly welded tuff; devitrified; very porous

146-3 --33 feet above base
Pale orange brown (10YR7/2); partially welded tuff; devitrified; porous; 1 percent partly collapsed pumice

146-4 --53 feet above base
Brownish gray (5YR5/1); dense, strongly welded tuff; devitrified; white and banded pumice (1 inch max.)

146-5 --90 feet above base
Light brownish gray (5YR6/1); dense strongly welded tuff; devitrified; 3 percent dark brown pumice (1/2 inch max.); 1 percent phenocrysts (1/16 inch max.)

147- One-fourth mile west-southwest of Davin Spring; NE1/4 NE1/4 sec. 9, T. 17 S., R. 24 E.; irregular blocky escarpment approximately 15 feet high

147- -- middle
Medium gray (N5); poorly welded tuff; very porous; friable; white, brown, gray, and black pumice; 2 percent small light brown lithics

151- Half a mile southeast of Pendleton Spring; SE1/4 SW 1/4 sec. 8, T. 19 S., R. 27 E.; covered slope

151-1 --(float)
Olive gray (5Y5/1); partially welded tuff; glassy luster; partly collapsed white and gray pumice (3 inch max.); eutaxitic texture

151-2 --(float)
Medium gray (N5); dense; strongly welded tuff; glassy luster; black colored, collapsed pumice (2-1/2 inch max.)

151-3 --(float)
Brown gray (5YR6/1); dense, strongly welded tuff; devitrified; eutaxitic texture; 2 percent gray pumice (2 inches max.); 1 percent colorless phenocrysts (1/16 inch max.); 1 percent irregular shaped gas cavities (1/16 inch max.)

182- West side of U. S. Highway 395 north of Burns, Ore.; NE1/4 NE1/4 sec. 21, T. 22 S., R. 31 E.; rim former; 83 feet thick

182-1 ---Base of unit
Medium light gray (N6); poorly welded tuff; very porous; colorless and brown shards; 8 percent white pumice (1-1/2 inch max.); 1 percent lithics (2-1/2 inch max.)

182-2 --2 feet above base
Brownish gray (5YR5/1); dense; strongly welded tuff; glassy luster; eutaxitic texture; a few collapsed pumice fragments (2-1/2 inch max.)

182-3 ---------------------------------------15 feet above base
Spherulitic; strongly welded tuff; 40 percent light brownish gray (5YR6/1) spherulites (1/2 inch avg.); dark gray (N3) glassy matrix; intensely fractured, crumbles readily

182-4 ---------------------------------------60 feet above base
Dark brownish gray (5YR3/1); dense, strongly welded tuff; devitrified; 10-15 percent irregular drusy gas cavities (1 inch avg.), druses have a colorless, thin lining of vapor phase minerals forming botryoidal surfaces

182-5 --82 feet above base
Brownish gray (5YR5/1); dense; strongly welded tuff; devitrified; slight eutaxitic texture; 1 percent pumice (1/2 inch max.); 1 percent lithics (1/2 inch max.)

182-6 --(float on top)
Pale red (10R6/2); partially welded tuff; porous; 3 percent reddish brown (10R4/6) pumice fragments